Ministry of Public Building and Works

Directorate of Research and Information

CONSTRUCTION RESEARCH

A Report on the Work of the Construction Research Advisory Council and the Construction Industry Research and Information Association.

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Construction Research

In his observations* on the Fourth Report from the Estimates Committee (House of Commons Paper No 351, Session 1967–68) the Minister of Public Building and Works accepted the Committee's recommendation that in 1970 the Ministry should publish a report to show how far the Construction Research Advisory Council (CRAC) and the Construction Industry Research and Information Association (CIRIA) are achieving the purposes for which they were set up.

The report which follows gives an assessment of the progress which CRAC has made in its strategic role of guiding the Ministry in the formulation of broad policy in regard to construction research. It shows that the Council draws upon wide knowledge of the industry, identifies in the broadest terms the national requirements in all branches of construction research, and indicates where effort needs to be applied. Part 2 of the report is a detailed account of the Council's work from its inception up to the present time.

The report also reviews the functions of CIRIA and shows that it is filling an essential role as the only research association concerned solely with the general research needs of the construction industry. Its responsibilities have been widened to cover the building side of the industry as well as civil engineering, but nevertheless its role is now more limited than was originally intended. This is because sufficient support was not forthcoming from the industry to maintain a national information and advisory service for the whole of the construction industry as was planned when the enlarged Association was formed. The attempt to provide such a service on the basis of voluntary subscriptions has therefore been abandoned and CIRIA's information activities are being restricted to its subscribing members. An appendix gives details of some of the more important projects which CIRIA is undertaking or has completed.

In presenting this report the Ministry of Public Building and Works has taken the opportunity to describe, in Part 1, the framework within which CRAC, CIRIA and other bodies concerned with research in construction operate. It is hoped that this outline of the respective responsibilities and functions of the main organisations active in this field will serve to extend knowledge of their work and improve understanding of the relationships between them.

*Cmnd 3886

Part 1

The Main Organisations Concerned with Construction Research

I Ministry of Public Building and Works

The Ministry's central role in construction research is to devise, with the guidance of the Construction Research Advisory Council (CRAC), a broad policy for the provision of an improved technology which will equip Government and industry better to satisfy the requirements of the community and of individual clients. The Ministry seeks to implement such a policy both through its own activities and through influencing and co-ordinating the activities of the various other bodies which contribute to the total research effort and which are briefly described later.

The Ministry's interest in construction research derives from its responsibility for:

1 sponsorship of the building and civil engineering industry;
2 promotion of greater efficiency in the industry, particularly by setting a lead as the country's largest owner and producer of buildings;
3 co-ordination of the activities of the various building development groups who are working in the MPBW and other Government Departments towards innovations of benefit to the industry generally and to its clients, particularly those in the public sector;
4 undertaking and sponsoring research and development work to support the Ministry's own substantial production programme;
5 the Building Research Station (BRS), of which it is the parent Department.

In discharging these responsibilities the Ministry has set out to evolve a national policy for construction research and development covering the following aspects:

(a) the scale and direction of research and development effort required to support all the activities of the construction industry and the associated professions (including the education and training of skilled manpower) and to enable the community's need for economical buildings of the right quality to be met;
(b) a suitable organisational framework within which the various bodies concerned with research and development can play their respective roles efficiently (these include industrial firms, research associations, Government research stations and development groups in central and local government);
(c) of not least importance, the means of securing effective and early application of research results.

It should be explained that the Ministry controls the Building Research Station's resources of money and staff. The Director is responsible directly to the Permanent Secretary of the Ministry for the Station's management; and a small committee of officials including the Director assists the Permanent Secretary in co-ordinating the work of the BRS and of the Ministry's Directorate General of Research and Development (DGRD), and deciding the allocation of available resources between them. A Steering Committee with broadly representative membership and an independent Chairman, responsible to the Minister, advises on the Station's programme and policy; but within the guide-lines provided by the Steering Committee the Station itself formulates its detailed programme of work.

II Construction Research Advisory Council

The Construction Research Advisory Council was established by the Minister of Public Building and Works in 1967 with the following terms of reference:

To survey the national need for construction research, to review

existing facilities, to consider measures necessary to encourage the expansion and more effective deployment of available resources, and to advise on the dissemination of research results.

The Council's task is to afford the Minister the advice and assistance he requires to enable him to formulate a national policy. Its secretariat is provided by the Ministry's Directorate of Research and Information, one of the constituent parts of the Directorate General of Research and Development (DGRD). As an advisory body the Council has no executive powers. The Ministry can take direct action on its recommendations only within the areas where resources are under the Ministry's own control, namely:

1 DGRD'S work within the Ministry;

2 the programme of extramural research projects sponsored and financed by the Ministry in universities, research associations and industrial firms;

3 Building Research Station.

The Chairman of the BRS Steering Committee and the Director of the Station both serve on CRAC. They are thus able to contribute to the formulation of the national policy within which the Station operates, and also bring first-hand knowledge of the Council's proceedings to bear upon the direction of the Station's work.

Details of the current membership of CRAC are given in Appendix 1. It will be seen that the Council includes representatives from all sectors of the industry as well as representatives of other Government Departments with construction responsibilities, the University Grants Committee and the Ministry of Technology. The Science Research Council is represented whenever appropriate.

Outside the area of its direct control the Ministry uses other means to bring about the adoption of measures to further the policy advocated by CRAC. The Ministry brings the views of the Council to the notice of other sponsors of research supported by public funds, such as the Science Research Council and research associations, and urges them to take co-ordinated action in accordance with the Council's recommendations. As regards the private sector the Ministry encourages the growth of research and development in appropriate directions by placing research contracts, although it looks to Construction Industry Research and Information Association (CIRIA) and the Heating and Ventilating Research Association (HVRA, see below) to be the main agencies for promoting collaborative research in the industry.

Part 2 of this report describes the work of CRAC up to the present time. The Ministry considers that the Council is amply filling the role intended for it and has made most useful progress in surveying the whole field of construction research. From its initial general discussions it has turned to more detailed consideration of particular sectors of the field, and its future work will involve further examination of the special problems of selected areas.

III Construction Industry Research and Information Association

CIRIA (whose Director is a member of CRAC) is a research association grant-aided by the Ministry of Technology. It came into being as a successor to the Civil Engineering Research Association (CERA) and with wider responsibilities, to provide a research

service for its members in both building and civil engineering as well as an information and advisory service for the industry at large.

In 1963 the Working Party appointed by the Minister (then Mr Rippon) to examine the need for improved research and information services had called for greatly expanded research, information and advisory services financed by a statutory levy on the industry together with some aid from Government. However, the industry opposed both the imposition of a statutory levy and the setting-up of a Development Council by means of which it could levy its own members. In July 1964 the Chairman of CERA proposed, on behalf of the major construction bodies, that as an alternative to a levy a scheme should be worked out for a joint research and information organisation for both building and civil engineering which would be financed by voluntary subscription and would build upon the experience of the Civil Engineering Research Association.

This proposal led to the formulation of plans for the reconstitution of CERA as CIRIA with assurances of financial support, at least from the major sectors. Government aid was offered by way of a grant of £2 for every £1 of subscription income devoted to information and advisory work, support for research activities, however, remaining on the previous £1 for £1 basis.

On this basis CIRIA was formed in July 1967 and began to operate in the new role. In March 1969, however, the Chairman reported to the Ministry that the Association was not achieving the degree of financial support from the industry necessary to establish and maintain a national information and advisory service on an adequate scale. In consequence, CIRIA sought substantial further income from Government.

The Ministry, although prepared to consider the need for some further contribution towards the information service, took the view that the cost of building it up to an adequate size required should be borne primarily by the industry. The Ministry then embarked on discussions with representative bodies in the industry to obtain their views on possible ways of raising funds for this purpose—in particular, by voluntary contributions, by establishing a Development Council with power to impose a levy under the Industrial Organisation and Development Act 1947, or by a compulsory levy under fresh legislation. These discussions prepared the way for a meeting of the National Consultative Council in July at which the Minister put the matter formally to the industry's representatives. The Council endorsed the Minister's view that information and advice should be paid for when required but expressed strong opposition to any levy and suggested that the demand for information and advisory services should be tested by a pilot-scale study undertaken by BRS. Having reviewed the situation in the light of these views, the Minister announced his conclusion that there was no realistic prospect that a viable information and advisory service could be provided on the basis of voluntary subscriptions by CIRIA's membership, and his decision that an experimental service on a fee-earning basis should be operated by BRS (this began in May 1970).

The Association has now ceased its general information and advisory activities and is devoting its resources, including Government support, to meeting the needs of its members. It sponsors research of interest to its members, undertaking little work directly with its own staff but generally placing contracts with other research associations, universities and the industry. CIRIA's information service is now restricted to its members, to whom it provides the results of the Association's research programmes. The membership of some 600 bodies comprises mainly civil engineering contractors and consultants, the larger building contractors and a number of local authority and larger public agencies. A note of some of the research sponsored by CIRIA is given in Appendix 8.

IV Other Research Bodies

The Heating and Ventilating Research Association undertakes research work within its own organisation and also provides a testing service. Like CIRIA its essential concern is with the collective interests of its members, and it receives a general supporting grant from the Ministry of Technology.

A number of other research associations have work relevant to construction in their programmes, including the British Ceramic Research Association (whose Director is a member of CRAC), Timber Research and Development Association, British Paint Colour and Varnish Manufacturers' Research Association, the Welding Institute, the Coal Tar Research Association, Water Research Association, Electrical Research Association, Welwyn Hall Research Association, British Iron and Steel Research Association, and British Non-Ferrous Metals Research Association. The Cement and Concrete Association, which makes an important contribution to construction research, is an organisation wholly financed by the industry. The Ministry has contact with these bodies both directly and through the Working Party on Building Materials of the Committee of Directors of Research Associations.

Work aimed at benefiting the general interests of the industry or the client, rather than the special interests of members, may be undertaken by research associations; normally work of this kind is commissioned by Government, which contributes funds specifically for the purpose.

The Science Research Council (SRC) also has an interest in construction research through the Aeronautical and Civil Engineering Committee of its Engineering Board. Under the Committee is a Building Panel which has accepted the general policy indicated by CRAC as providing guide lines for its own activities. The role of the SRC, acting on the advice of the Building Panel, is to support promising research work and post-graduate education in the universities generally. The Panel is seeking to influence the direction of research in the universities and to exercise a measure of co-ordination: essentially, however, it responds to requests from the universities. On the other hand the MPBW channels its support to the universities with the object of promoting research work required to meet specific needs for the industry, and financial support is given selectively for the purpose of creating or expanding research facilities necessary for such work. The MPBW policy is to encourage the concentration of particular universities upon certain subjects, so as to build up centres of expertise.

Part 2

The Work of CRAC

This part of the report outlines the Council's work so far, with the aim of making its recommendations more widely known. It includes in Appendices 3–7 a series of reviews of particular aspects of construction research: engineering services and environmental design, materials and components, economics, maintenance and computer applications. These reviews and others which will be undertaken in the course of the Council's future work are intended to provide a basis for considering the needs for research in particular fields and how they should be met. The Council would welcome discussion and comment so that it can where necessary adjust its policies in the light of a wider consensus of views. The reviews should also enable those responsible for initiating research to be more aware of the existing distribution of effort and resources among subjects and institutions, and to shape their policies within a national pattern.

I Scale and Direction of Research and Development

Biennial surveys by the Ministry's Directorate of Research and Information had built up a picture from 1964 onwards of the scale and subjects of applied research on construction, and they provided the starting point for CRAC's reviews of research needs and the organisation of work in various parts of the field. A summary of the results of these surveys, given in Appendix 2 to this report, is concerned mainly with public sector expenditure, since information on private sector research and development is restricted for commercial reasons.

The analysis shows among other things the growing interest of universities and colleges in construction problems, and the increasing range of subjects studied. The problems of research in this sector are discussed below.

The level of research expenditure, at 0·5 per cent of the industry's turnover, appears to be low compared with other industries. There is also imbalance between relatively well supported areas, notably civil and structural engineering, and others such as architecture, services and construction processes, which are neglected by comparison. Among these neglected aspects are those subjects which concern human needs and the environment in and immediately surrounding buildings. CRAC is reviewing progressively the needs for research in various aspects of construction, to establish where further effort is required and how it should be provided. The scientific staff of the Ministry's Directorate of Research and Information, which provides support for CRAC, keep in close touch with bodies which undertake and those which finance research so as to supplement the information from the survey.

II Expansion of Construction Research

At an early stage CRAC considered the general case for expanding overall the share of Government research and development resources devoted to construction. This involved to some extent anticipating detailed surveys of the field, but it had the advantage of lending immediacy to the Council's deliberations. It was obliged to clarify the economic and social justification for research in this field, and particularly that in the public sector, about which there are common misconceptions. It was evident that there was no universal type of justification for research programmes. While some offered straightforward commercial benefits, others were at least in part concerned with productivity, import substitution, etc., which benefit society as a whole rather than individual organisations. Some of the most spectacular economic benefits have come from research concerning design, but there was also important research on safety, protection of consumers and

ways of meeting demand for higher standards of building performance. Other research provided guidance for policy-makers in industry or Government. Much research was directed to social needs and brought benefit to clients and users of buildings rather than contractors or manufacturers.

CRAC also recognised from the start that research must not be divorced from the means of applying its results. This consideration highlighted the importance of public building authorities, which are in the special position of both financing large repetitive programmes and employing many of the architects, engineers and surveyors who design the schemes. Because they are also clients for the work and have to find the funds, these bodies have a greater incentive than independent consulting firms to undertake research; while private building clients rarely have their own design staff and, having generally only small building programmes, are less able to derive benefit from research. The formation of larger local authorities will increase the scope for work directly related to building programmes. Taking the industry to include all who serve the client, public design offices are part of it. Thus research in these public bodies is in a real sense within the industry. The Government's responsibility for consumer protection and the national economy is a further argument for it to undertake or finance certain types of research.

The recent rate of growth of construction research suggests that it would be feasible in terms of recruiting qualified staff to double the 1968 level of research in the public sector by 1972. Consideration of the research needs in some of the more neglected areas, coupled with more general comparisons between this and other industries, led the Council to propose as a target an increase from £8 million in 1968 to £15 million in 1972, representing the doubling of research in some areas and a rather slower rate of growth in those which are relatively well established, like civil and structural engineering. Detailed reviews of specific fields (such as engineering services) confirmed that this scale of expansion was desirable and practicable.

Continuing and accelerated growth of research effort in the next few years poses a challenge to Government and the industry. The Council was considerably encouraged by the evidence of support in both quarters for its conclusion that research for the construction industry required expansion, and in particular a larger share of Government research and development finance. But it seemed clear that an ambitious programme of growth could not rely entirely on the allocation by a large number of separate bodies of more funds for research in construction subjects. The Council felt that expansion of research activity must follow rational lines; and from its initial survey of the general situation it concluded that it was necessary for the Ministry of Public Building and Works to give a lead not only by continuing the growth of BRS but also by supporting a large programme of external research in universities, research associations and other bodies connected with the industry. The Council further decided to make a systematic examination of research needs in more detail in order to lay down a pattern of expansion for the guidance of all concerned. With this aim the Council embarked on a series of reviews of particular fields of construction research, starting with engineering services and environmental design. The results of those undertaken so far are summarised below and given in more detail in Appendices 3–7. The reviews are continuing, with the object of covering all important aspects of construction and arriving at a comprehensive framework of policy that will match the developing needs of the industry and its clients.

III Responsibilities of the various research agencies

It was also necessary for the Council to consider what are the main agencies for construction research, and to identify their special characteristics, in order to assess the

potential contribution of each within the various fields. The Council found it convenient to divide the research bodies into those of a private nature and those which are wholly or partly supported by public funds (though some organisations do not fall completely into one category or the other). Within the public sector, in which research associations are classified for present purposes, are Government establishments and development groups, and universities and colleges. Appendix 2 gives the most recent analysis of research by these various bodies.

The Government bodies' work is largely concerned with the requirements of public construction—design development and value for money—and with the protection and needs of the community: its results are therefore much used by professional staff in public offices and by bodies which set standards and make regulations for building.

The research associations work on problems of interest to their members and receive Government financial support as an expression of the Government's interest in encouraging collective research aimed at advancing technical progress in industry. (It should be noted that CIRIA operates mainly through management of research contracts placed with other agencies, and does not undertake the work itself: for this reason it does not feature in the statistics of research undertaken by various agencies.) Perhaps their most important feature is that they provide a means by which firms in industry can agree on common research aims and undertake the necessary research in close association with the ultimate user of the results in industry.

The educational sector has a key part in preparing the industry's professional recruits for practice in industry and has traditionally done research as a counterpart to this role: its special characteristics are ability to incorporate research into teaching and to attract new men to a field of research; but (unlike Government bodies) it lacks resources for a concentrated and long-term attack on problems and (unlike research associations) lacks continuing contact with the industry.

The Council sees a need for expansion in all groups if the industry's research needs are to be met. The statistics show that, despite its limitations as a short-term influence for change, the educational sector has grown the most rapidly and is likely to continue to offer a large part of the overall potential for growth. The Council attached high priority to improving its research and development support for construction education but recognised that the dispersed and unco-ordinated effort in universities made it difficult to do this effectively.

One of the ways in which this situation can be improved is to finance institutes and units on a continuing basis, so that the bulk of further expansion is directed to a few strong centres, which have the resources to build up contacts with users of their results. Much of the additional MPBW support for construction research in universities should thus provide for continuity of effort by providing support for periods of at least five years and aim at co-ordinating effort. The recommendations described below for an engineering services research institute and research units in materials and economics fall into this pattern.

CRAC has given attention to the definition of the role of the Building Research Station and the activities appropriate to it. Arising from its position as the Government station with the largest and broadest interests in construction, BRS's work leads to benefits of various kinds (in brackets, as percentage of 1968 programme):

better understanding of users' needs as a basis for design and regulation (14 per cent)

foundations for specification of performance and methods of testing and quality control

(development of actual specifications, etc., may be undertaken elsewhere) (27 per cent)

improvement of efficiency in the design and production and assembly processes, including assistance to public sector development groups (36 per cent)

technological advances in manufacture including use of natural resources and development of new materials (15 per cent)

knowledge of economic and managerial aspects of the industry as a basis for Government policy formulation (8 per cent).

Within these categories, BRS should concentrate on work which cannot be, or is unlikely to be, done within industry or the professions: this includes some work which is not of immediate benefit to Government, such as development of new materials and methods of construction up to the point where firms are prepared to exploit them under licence.

The special strengths of BRS include its continuity, resting on nearly 50 years' achievements, the substantial scale on which it can operate, and its ability to field multidisciplinary teams. The Council concurs with the recommendation of the Steering Committee that these strengths should be maintained; the Station should give particular emphasis in its continuing expansion to the fields of environmental design and engineering, to production (particularly communication problems) and systematic design (in architecture and engineering). The Council also endorsed the increasing effort to get BRS results applied in the industry, and noted that the Station would take suitable opportunities for collaborative and sponsored projects, provided its ability to serve central government was not thereby diminished. In recent years the Station's staff has grown by over 3 per cent annually. While this is a substantial absolute increase in research resources, it compares with 13 per cent for construction research as a whole. It seems clear that the Station cannot match this rate, although it could increase its rate of growth significantly for a period of years. For this reason, while recognising that BRS would continue to be the main centre of research, CRAC decided that it must give most of its attention to expansion elsewhere.

IV Engineering Services and Environmental Design (see Appendix 3)

The needs for research on problems of designing engineering plant and services, designing the environment for working and living in buildings and managerial aspects of the installation of services, were considered by a Special Panel under the chairmanship of Mr F A Pullinger. CRAC agreed to the Panel's recommendation for a three-pronged attack. First, as already mentioned, there would be high priority within the continuing growth of BRS for the programmes of the Environmental Design and Engineering Division. Second, the Panel gave a general welcome to the Heating and Ventilating Research Association's plans to widen the range of its services and increase its research programme, and it recommended Government departments to assist this expansion. As a result, MPBW has embarked on a series of research contracts with the HVRA. Third, the Panel observed the considerable growth of interest at universities and colleges in environmental engineering research and in starting courses at first and higher degree levels; though it was apparent that unless this interest was focused in fewer centres it could not make sufficient impact on potential recruits or the industry. In this sector the Panel therefore recommended that a research institute should be set up in Glasgow, where both universities have interests in this subject, a recommendation which the Ministry is taking steps to implement in consultation with the other parties concerned. In accepting the Panel's recommendations about the pattern of research, the Council endorsed its hope that these would in due course lead to concentration of university research in this subject at

a few strong centres, able to maintain close contact with industry and the professions, and that these policies would promote the important objective of enhancing the influence of services engineering in the design process.

V Materials and Components

The Council considered a review of needs for research on materials and components (Appendix 4) and saw an expanding role for research associations in bridging the gap between manufacturers and contractors, for instance by developing methods of producing and handling components with desirable properties such as freedom from maintenance. The Ministry intends to develop activities in this area through research contracts. The main role of the universities would, in the Council's view, be to study the basic properties of materials, and it envisaged the formation of research units as a possible development. The main emphasis of BRS work is likely to be on development of new materials and of components in association with industry and with Government development groups. The Government should also, in CRAC's view, be ready in appropriate cases to support developments by individual firms.

The most important current development in this field is that a new laboratory will be set up, associated with the Agrément Board, to work on performance specifications for materials and components in support of British Standards, and to undertake test development. The establishment of this laboratory will remove work that competes with longer-term projects at BRS, and will provide resources to meet the expected growth of demand for testing and performance specifications in the 1970's.

VI Construction Economics (see Appendix 5)

The review of construction economics research considered the needs for research relating to the functioning of the industry as a whole, the functioning of individual firms or projects, and the economics of the product (including study of costs).

About £100,000 was spent on these subjects in 1966, of which four-fifths was in Government research stations (mainly at BRS) and in research associations. Universities' interest in this subject is increasing, and consideration has been given to the means by which their potential contribution can best be realised. The framework approved by CRAC includes a BRS research team working on empirical problems requiring large resources, and a unit at a university studying each of the three subject areas identified above. The Ministry is now surveying possible centres for these units.

VII Maintenance (see Appendix 6)

Repairs, maintenance and minor works to building and civil engineering structures account for expenditure of about £1,650 million a year in the United Kingdom, or a third of all construction expenditure. Having regard to the economic importance of maintenance, its neglect as a subject of study and the lack of any coherent industrial base, the Minister of Public Building and Works has set up the Committee on Building Maintenance to advise on the measures necessary to obtain significant improvement in its technical and economic performance. The research needed to provide a basis for action in this field is in many cases linked into a subject that is not confined to

maintenance, e.g. performance of materials. It is, however, possible to identify projects amounting to 10 per cent of the effort in the sector supported by public funds, about £500,000 a year; and of these over two-thirds are concerned with materials, a fifth with climatology and structural performance, and a tenth with maintenance operations. CRAC endorsed proposals for increased research emphasis on maintenance, including more attention to the durability aspects of materials under development, and to the influence of design on maintenance liability; it attached particular importance to operational studies leading to more efficient organisation of maintenance. It also welcomed the Committee's ideas for developing services of information and advice. BRS is currently reviewing its possible contribution to this field of study, and the Ministry is also considering the scope for research contracts on operational and materials aspects.

VIII Computer Applications (see Appendix 7)

In 1966 the Minister of Public Building and Works appointed a Committee on the Application of Computers in the Construction Industry. Part of its task is to review existing research and development, on which central and local government, universities, and research associations spent £500,000 in 1968 and to define research and development needs. While in the longer term the impact of the computer must be to promote the integration of the building process, it has proved necessary to look in the shorter term at developments in relation to structural engineering, contracting, architecture, etc., while also initiating studies crossing existing boundaries. On the Committee's advice, the Ministry is developing an integrated software system for structural engineering, GENESYS (General Engineering System). Suites of problem-solving programs are being written for operation with GENESYS, which provides a basis for co-ordination of further development in this field and also offers prospects of application to many other areas in computer-aided design. A GENESYS Centre has been formed at Loughborough University to develop the system and make it available to the industry from 1971 onwards. CRAC sees GENESYS as a most important development for the construction industry, which should receive wholehearted support.

The Council recognised the great potential importance of studies of computer-aided design at the National Physical Laboratory and Cambridge and Edinburgh Universities, and emphasized the need for work on systematic methods of design and construction at BRS and selected universities to provide a sound foundation for the extended use of computers in construction.

IX Construction processes and mechanisation

Work concerned with the physical processes of construction and the development and use of mechanical aids represents around a tenth of current construction research, and shows little sign of increasing in scale. The construction industry is generally considered to have room for further introduction of managerial innovations and mechanical aids, and there have been examples of very large benefits from their application. The reasons for the low level of research and development in these fields include: the complexity of many of the problems, which involve the interaction of mechanical aids with design, components, and construction methods; the number of interests whose collaboration is needed, including the construction plant industry as well as the various sides of the construction industry; the obstacles to the introduction of new methods, particularly those requiring mechanical plant, which are posed by the need to train a highly mobile labour force and to find resources for investment in capital and managerial techniques

in a very competitive industry; and the relatively high costs of experimental work in these fields. Most current research is undertaken by manufacturers and contractors. Among Government establishments, the Road Research Laboratory has work on earth-moving and road bridge construction, while the Building Research Station has increasingly directed its attention to the complex problems involving plant, design, materials, and methods of construction. The Military Engineering Experimental Establishment is used for testing mechanical construction plant. General surveys of the fields of processes and mechanisation by CIRIA and the Directorate of Research and Information showed the Council that more work was needed to identify all the specific areas where research initiatives would be effective; industrial participation in the formulation and finance of research was particularly appropriate in fields where the benefits would take the form of increased efficiency, although the client interests represented by central government should also take part and provide support. The Council decided to initiate further discussions on research in these fields by experts representing the various interests.

X Structural stability

The statistics summarised in Appendix 2 might suggest that research on problems of structural engineering was more than adequate by comparison with other aspects of construction; but the Ronan Point disaster in 1968 called attention to the urgent need for work on a range of problems concerning the stability of structures and the dynamic forces, such as wind and explosions, which act upon them. Following the disaster BRS and many other bodies collaborated in the investigations and the interim revisions to regulations and codes of practice. Two years later, there is a need to see that longer-term studies to put structural design knowledge on a sound basis are adequately financed and co-ordinated. A new panel of CRAC is being set up to bring together practising structural engineers, those carrying out research, and bodies responsible for regulations and codes of practice, both to recommend what further action is urgently needed on research relating to structural stability (including the influence of explosions and aerodynamic forces), and to undertake a review of longer-term programmes and the organisation of the national research effort in this field.

XI Dissemination and Application of Research

A continuing concern of CRAC is for the improvement in the translation of research into practice. This is not a simple or isolated problem: it is best seen as an aspect of the management of research at all levels—the project and the programme, the unit and the institution, the agent and the sponsor. Effective dissemination depends to some extent on the organisation of fields outside CRAC's immediate terms of reference, such as standards, information, and education. New demands for research arise from the need to match progress in these fields—for instance, the move towards a performance specification basis for British Standards is throwing up questions requiring research; but equally, progress in those areas must accompany expansion in research.

Construction research is necessarily an applied science and is undertaken for the practical benefits it can offer, not as a contribution to knowledge. BRS is giving increasing emphasis to the application of its results and has set up sections to analyse past experience, to advise on the marketing of recent results to the industry, and to assess the prospects of project proposals. One reason for concentrating research in centres with several project teams and a measure of continuity is that this permits them to develop

contacts with users of research and expertise in putting it across. Research associations have in-built advantages in this respect, with their industrial membership. University research requires special attention to compensate for its frequent lack of continuity and industrial contacts. Among promising moves to bridge these gaps are the proposals for a research institute at Glasgow and for research units in materials and economics, which MPBW has under study and negotiation, the Min Tech sponsorship of industrial units within universities, providing an active link between industry and technological departments, and the growing practice of running short courses and seminars for practising engineers on recent research and current problems. CRAC is particularly concerned about the problems surrounding the provision of mid-career training for professional staff, since this is potentially a very effective method of disseminating advances in knowledge and practice. The construction professions are not alone in their growing recognition of the need for updating those in mid-career: they have, however, special problems, including the large proportion of some construction professions which is outside the scope of industrial training schemes, and the fact that some professional staff work for central government, some for local authorities, and some for firms in various industries besides those in private practice. The institutions are evolving common policies on training, but have found no ready solution to the problem of finance. On the other side of the coin, there is a danger that too many bodies will independently offer courses in competition. CRAC has invited the Ministry to discuss with the other Government departments concerned whether special steps are needed to secure the future development of mid-career training for the construction professions, and to examine the precedent of Min Tech's industrial liaison appointments, which are one way of providing administrative support for the organisation of courses. The Council itself proposes to look further at the use of courses as a part of the dissemination machinery of established research agencies: the Cement and Concrete Association and BRS provide models for this, but the dissemination of results of the work of smaller bodies such as university research units, and methods of putting across advanced technologies such as computer applications, require special attention.

The Council will be keeping the dissemination aspect of research under continuous review, and will regard this aspect as an important feature of any new organisations set up as a result of its recommendations. It will seek ways of improving the usefulness to the industry of work undertaken in organisations too small or specialised to have direct access to means of dissemination.

Close contact between research and the industry it serves is also the best way to train people in practice to recognise problems which research could resolve and to commission the work required. By making dissemination and industrial liaison an integral aspect of research activity, central government can stimulate financial support and collaboration from other bodies including local authorities, contractors, and manufacturers. CRAC sees increased Government support for research as a catalyst for a more vital technological atmosphere in the industry.

XII Future Work

There will thus be three important tasks for CRAC in the next two years. First, it must explore more deeply the complex problem of ensuring that the efficiency of the dissemination of research results matches up to the quality of research and the growing resources devoted to it. As has been seen, this problem must be attacked on a number of fronts, and has implications for the organisation of research to which the Council will attach great importance in considering future plans for institutes, units, etc.

Secondly, it must review further important areas in the construction field, ranging from long-established subjects to others which have hardly been adequately defined yet.

Thirdly, it must stimulate wider discussion of these questions. The recent and prospective expansion in all aspects of research on construction must be adequately co-ordinated, but it would not be possible or desirable in such a diverse field where there is inevitably a multiplicity of sponsors and a growing number of important research centres, to do more than exercise a general co-ordinating function. The Council considers that it can contribute best to this general co-ordination of effort through the publication of its policies and the analyses and reviews on which they are based, in the hope that they will provide acceptable guidelines for all those concerned with the sponsorship or management of construction research. The Council hopes that this publication will stimulate a continuing debate on the scope and direction of research which will contribute significantly to the further evolution of policy.

APPENDICES

APPENDIX 1

Membership of Construction Research Advisory Council

Sir Michael Cary KCB (Chairman)	Permanent Secretary, Ministry of Public Building and Works
Dr N F Astbury CBE MA ScD FIEE FInstP FICeram	Director, British Ceramic Research Association
B P Beckett Esq B Arch (Dist) Dip TP FRIAS FRIBA AMTPI	Chief Architect, Scottish Development Department
W E Tatton Brown Esq CB MA AA Dip ARIBA	Chief Architect, Dept of Health and Social Security
Dr A R Collins MBE DSc PhD FICE MIStructE	Director, Construction Industry Research & Information Association
Dr A H Cottrell FRS	Deputy Chief Scientific Adviser, Cabinet Office
J B Dick Esq MA FInstP	Director, Building Research Station
P W Grafton Esq FRICS	Partner, G D Walford & Partners
D M Henderson Esq BSc	Director, John McAdam & Sons Ltd, Aberdeen
L C Kemp Esq	Secretary, Operatives' Side, Civil Engineering Conciliation Board
Dr O A Kerensky CBE FRS DSc FICE FIStructE FInstHE	Partner, Freeman Fox & Partners
W D Lacey Esq CBE ARIBA AMTPI	Chief Architect, Department of Education & Science
Dr E Lee MSc PhD	Deputy Controller, Ministry of Technology
J G A Marriott Esq MA AMICE	Robert Marriott Ltd, Rushden
Prof P B Morice DSc PhD FICE FIStructE	Department of Civil Engineering University of Southampton
Prof J K Page BA	Department of Building Science University of Sheffield
E R Parrinder Esq FRICS FIArb	Davis, Belfield & Everest, Chartered Quantity Surveyors, Chairman of BRS Steering Committee

F A Pullinger Esq CBE MA CEng FIMechE	Chairman, G N Haden & Sons Ltd
J T Redpath Esq CB MBE ARIBA	Director-General of Research and Development MPBW
W J Reiners Esq BSc	Director of Research & Information MPBW
Dr E J Richards OBE DSc FRAeS	Vice-Chancellor, University of Technology, Loughborough
A Thompson Esq	Under-Secretary, University Grants Committee
R T Walters Esq CBE FRIBA MIStructE	Controller General, MPBW
F J Ward Esq	Under-Secretary, Ministry of Housing & Local Government
H J O Weaver Esq	General Secretary, National Federation of Construction Unions
Sir Hugh Wilson CBE FRIBA MTPI	Hugh Wilson & Lewis Womersley Partnership
Sir Kenneth Wood BA FCA	Chairman, Concrete Ltd
D Baldry Esq (Secretary)	Ministry of Public Building & Works

APPENDIX 2

Construction Research and Development Statistics

1 The third survey of construction research and development has been completed and the results relating to projects active in 1968 are now available. Details of the projects together with an analysis of the distribution of expenditure have been published as an R & D Bulletin. This analysis is restricted to public sector expenditure since private sector expenditure is available only in aggregate and at a later date.

2 The estimated total expenditure in the public sector (including grant-aided research associations) was £8 million in 1968 compared with £5·8 million in 1966 and £3·9 million in 1964. These figures correspond to an increase of about 40 per cent from 1966 to 1968 and 50 per cent from 1964 to 1966. It is possible that some increase in the coverage of the survey from 1964 to 1966 explains the higher rate of increase in the earlier period. Some allowance must be made for inflation over this period, however, and a better guide may be provided by relating the research and development expenditure in the public sector to the value of gross output of the construction industry in these years. The corresponding figures are 0·18 per cent (1968), 0·14 per cent (1966), and 0·11 per cent (1964), equivalent to an increase of about 30 per cent for both 1966–68 and 1964–66, or 13 per cent per annum.

3 The analysis by agency groups of expenditure on research and development in the public sector (Table 1) shows that educational bodies (mainly universities) had by far the greater percentage increase over the period, while research associations expanded at a significantly lower rate than average for the sector. It follows that educational bodies increased their share of the public sector effort (to 22·5 per cent) while the share of the research associations declined (to 11·2 per cent).

Table 1

Analysis of Estimated R & D effort within Group in the Public Sector

(£000s (nearest £10,000) and percentage of total)

Group	1964	1966	1968
Government departments	2240 (57·7)	3480 (59·7)	4410 (55·0)
Educational bodies	670 (17·3)	1100 (18·8)	1820 (22·5)
Other Public Authorities	400 (10·3)	620 (10·7)	910 (11·3)
Research Associations	570 (14·7)	630 (10·8)	900 (11·2)
Total	3880	5830	8040

4 Not all estimated expenditure can be classified by subject. This arises from failure of the respondent (mainly university departments) to make a return at all or by the return of a lump sum not supported by project descriptions. In 1968 the expenditure which could be classified was nearly 90 per cent of the estimated total. The principal subject areas used for classification purposes in 1968 (see below) differ in some respects from those used for 1966 and 1964 and the results for these years in Tables 2 and 3 have been amended accordingly.

Table 2

Distribution of Classifiable Expenditure by Subject Area

Subject Area	Expenditure £000 and (%) of total		
	1964	*1966*	*1968*
Engineering, soil mechanics hydraulics	1446 (37·7)	1967 (36·9)	2819 (39·9)
Architectural design, function, performance	847 (22·1)	1415 (26·6)	1407 (19·9)
Materials	643 (16·8)	831 (15·6)	1299 (18·4)
Economics, efficiency, management	188 (4·9)	302 (5·7)	706 (10·0)
Services	461 (12·0)	483 (9·0)	527 (7·5)
Construction, plant	251 (6·5)	336 (6·2)	305 (4·3)

Over the three surveys the proportion of effort devoted to engineering, materials and construction has remained remarkably constant and fluctuations are probably within the limits of accuracy of the exercise. The evidence suggests that relative effort in economics has risen but fallen in architectural design and in services. The fall in architectural design derives mainly from Government departments and may be attributable to the lack of expansion of the development groups in these departments.

Table 3

Balance of effort in Agency Groups in the Public Sector (percentage)

Subject Area	Government Departments			Educational Bodies			Other Public Authorities			Research Associations		
	1964	*1966*	*1968*	*1964*	*1966*	*1968*	*1964*	*1966*	*1968*	*1964*	*1966*	*1968*
Engineering	35·9	31·6	39·0	63·5	69·5	50·9	35·6	32·5	29·2	12·9	24·2	38·2
Architectural Design	30·2	33·7	23·5	13·3	13·0	20·4	13·5	19·4	13·5	6·6	10·8	6·9
Materials	16·2	16·7	18·6	6·2	5·4	11·7	6·6	9·2	13·3	39·8	28·7	33·6
Economics	6·4	6·2	10·2	5·1	5·6	9·5	2·4	9·2	14·1	0·1	0·2	5·4
Services	1·2	3·0	3·3	8·6	4·6	5·9	41·1	28·0	29·8	40·2	34·3	8·5
Construction	10·1	8·8	5·4	3·3	1·9	1·6	0·8	1·7	0·1	0·4	1·8	7·4

5 The balance of effort in each of the four groups in the public sector over the years 1964, 1966, and 1968 is shown in Table 3.

The general pattern reflects, of course, that shown in Table 2. Points of particular interest are the signs of less concentration on engineering at universities and colleges of technology and their continuing minimal effort in construction; the continuing preoccupation of Government departments with engineering and a reduced interest in construction: and the marked decline in work on services by the research associations (mainly through the reduction of work at the British Coal Utilisation Research Association).

6 Finally the distribution of the total classifiable expenditure in each subject area in 1968 is analysed by agency group in Table 4.

Table 4

Distribution of effort within Subject Areas by Agency Group

Subject	Total Expenditure £000	Govt. Depts.	Educational Bodies	Other Public Authorities	Research Associations
Engineering	(2819)	57·6	23·2	8·5	10·7
Architectural Design	(1407)	69·8	18·5	7·9	3·8
Materials	(1299)	59·7	11·6	8·4	20·3
Economics	(706)	60·4	17·3	16·4	5·9
Services	(527)	26·4	14·4	46·5	12·7
Construction	(305)	73·9	6·9	0·1	19·1

The effort of the Government departments (including their research stations) predominates in all subject areas with the exception of services. This also applied in 1966 and 1964.

7 Research and development expenditure in industry for 1968 is not yet available and Ministry of Technology statistics will not be available until early 1970. These can then only be used to provide a very approximate estimate of research and development applicable to construction. In the 1966 survey between £9 million and £13 million was thought to be a not unreasonable estimate of research and development expenditure within the private sector of the industry, or about twice that within the public sector.

Classification by Main Subject Areas (1968)

Engineering, Soil Mechanics, Hydraulics

The structural design and behaviour of structures and components, soil mechanics including the constitution of soils and strata, hydraulic, hydrological and geophysical studies; associated measuring and testing techniques.

Architectural Design, Function, Performance

Studies in the design of structures to provide a suitable environment for human use and occupation including the design of components and elements, functional performance and the needs and reactions of users and occupants.

Materials

The manufacture, properties, durability and use of constructional materials; the properties of their constituent minerals; associated testing and analytical methods.

Economics. Efficiency, Management

Cost studies, the training and use of labour, communication within the building team and studies of the structure and management of the industry.

Services

The design, installation and operation of mechanical, electrical and piped services, including design criteria.

Construction, Plant

The physical process of erection, alteration and repair including the plant and equipment used and the handling of materials and components.

APPENDIX 3

Review of Research on Engineering Services and Environmental Design

(Based on papers presented to the Council in June 1968 and June 1969)

1 The importance of engineering services in buildings is increasing in several ways. Their initial cost has become a larger proportion of the total cost of buildings, and their operating costs are a mounting item in occupiers' budgets. Users of buildings are demanding higher environmental standards, controlled conditions for computers, and more provision for the use of electrical equipment. The space occupied by engineering plant and the layout of services distribution must now be incorporated from the start in successful designs, and not added afterwards. One measure of the importance of this element in new building is that it accounts for over £500 million a year. Services thus represent a third of the cost of new construction: in individual large buildings (e.g. hospitals) their cost may approach or even exceed 50 per cent of the capital outlay; maintenance of services accounts for a further £330 million a year; and their operation (fuel costs, etc.) is a further large item in building owners' budgets. This situation creates in CRAC's view an urgent need for more research, information, and education on environmental engineering and design.

2 The Building Research Station pioneered the study of building physics and the design of services. The Heating and Ventilating Research Association was set up in 1955, and other research associations have done important work in this field since the war. In recent years a large number of universities have become interested in these subjects of research, and in providing specialist courses. A review of the level of research activity in this field, however, showed that the expenditure by public bodies (other than nationalised industries) classifiable under this heading is around £600,000 a year or 0·08 per cent of the turnover of the comparable part of the industry. Its lack of growth from 1964 (when the Ministry of Public Building and Works first surveyed construction research and development) to 1968 is in sharp contrast not only with other aspects of research, but also with the rapid expansion of expenditure on services in buildings. While this deficiency is to some extent offset by the research efforts of the fuel and plant manufacturing industries, for which no reliable figures are available, environmental engineering research specifically directed to the needs of the building design team and the installation contractor remains at a very low level. CRAC has therefore given this subject very high priority in the expansion of research, and has suggested as an immediate target the doubling of present effort.

3 Educational and research activities are connected in several ways. Much research is conducted in universities and colleges, and it has a part in establishing the educational basis of the subject and its academic standing. The training of new entrants to the profession, and courses for those in practice, are among the ways in which results of this work are disseminated.

4 Arrangements for training mechanical and electrical engineers specialising in building services have hitherto failed to recognise sufficiently the services engineer's importance in the design team. This growing element of buildings has until recently been largely ignored in architectural education, and many problems have arisen because of failure to integrate services and structure in building projects, or to provide internal environments that function satisfactorily. The National College of Heating, Ventilation, Refrigeration and Fan Engineering, set up soon after the war, has recently instituted a first degree course, and a few universities have started or are planning such courses. Rather more universities run post-graduate courses or give attention to this aspect of building in architectural and other building syllabi. These important initiatives are only a start towards what is needed, especially since the numbers passing through the degree courses are small.

RESEARCH NEEDS

5 It is convenient to divide the fields for research into six areas:

5.1 User Needs

The fundamental physiological and psychological needs for thermal, visual and acoustic comfort (and their relation to industrial productivity, accidents and health) are changing and should be reviewed in detail. This is the case for both dwellings and work places, particularly where manufacturing processes may affect some of the requirements or may produce uncomfortable environment. The use of hot and cold water, the needs for sanitary facilities, the composition and quantity of household waste, fire-fighting, power and communications in all types of building must be kept under review and trends forecast. All this information is basic to the design of the several services and of the equipment for them. Changes in temperature and illumination needs have caused big increases in costs in use over the past 20–30 years and this alone may serve to stress the importance of research in the field of user needs.

5.2 Architectural Physics

Improved knowledge of the behaviour of buildings is a prerequisite to the design of engineering services within them. The subject has been relatively well served but there is still work to be done on heat flow (especially transient) and on solar gains, wind effects, noise generation and propagation, artificial and natural lighting, and on meteorology and micro-climate.

5.3 Engineering Designs of Systems and Components

When the basic requirements are known the engineering design of components and systems required to fulfil them needs to be studied. In doing so account must be taken of psychological and technological needs, economic factors and the interaction between the building and the services, as well as between the services themselves. Part of this work is of a general character of interest to all designers and building owners, and part is specifically for the design and manufacture of particular components to meet a given need or for securing the maximum use of particular fuels. Studies of the effect of building construction and configuration on costs in use of engineering services fall within this area. Other subjects within this field are: development and use of new materials; dimensional co-ordination; standardisation and variety reduction; the effect of industrial building methods on engineering service design; studies of total energy and district heating; disposal of waste including utilisation for heat; heat transfer; fluid flow and low-speed aerodynamics.

In component design much of the progress of the next decade will be in control engineering, packaging of plant to reduce site labour and design, and in size reduction of plant or systems by increasing pressures, velocities or temperatures, or similar means of electrical engineering. Development may be expected within manufacturers' organisations but in the public sector there will be a need both to test and to evaluate.

5.4 Contract and Design Management

This area includes management of design, estimation and contract control, including integration with industrialised production methods and controls. Some work has already been done by HVRA in the field of prefabrication and site management of heating and

air-conditioning contracts, with clear indications of greatly improved productivity. Much more remains to be done and the studies extended to the other mechanical and electrical services, and to the processes of design.

5.5 Computer Application

The application of computers to design of both buildings and engineering services offers great potential, especially in optimising the two in association. So far, the surface has only been scratched by the provision of a few elementary programmes for system design and critical path analysis. The current study of data co-ordination and coding by BRS, HVRA, and MPBW, as well as work by COSTIC in France, points the way to a completely integrated plan for the design and construction of a building and its services as well as a reliable prediction of its costs. A great deal of work is necessary before this ideal is realised. The application of computers in financial and contract management affairs follows well-trodden paths, but more remains to be done in developing systems for the small user and for specific areas such as estimation.

5.6 Operation and Maintenance of Installations

This area includes commissioning, test operation, control and maintenance of completed installations. Too little is known of the performance in the field in relation to the stated user needs and of annual operating costs of engineering services, particularly those of heating and air-conditioning, by any fuel. In a climate so variable as ours, and with widely varying occupational habits, the need for a disciplined approach to observation, analysis and feed-back to designers is apparent.

CURRENT RESEARCH ACTIVITY

A The Private Sector

6 Invention of equipment and its commercial exploitation by manufacturers and, to a lesser extent, by fuel suppliers has probably been the major source of innovation and progress in the servicing of buildings, and will clearly continue to have great influence because the commercial incentive and financial resources are there.

7 The Fuel Industries

Each of the fuel industries finances research. The major oil companies and the coal, gas, and electricity industries have establishments whose programmes include development of heating methods and other aspects of the use of their products. Of these, electricity has the widest variety of applications in buildings. At the Capenhurst Research Laboratory (established in 1965) there is a full-scale investigation of the light-with-heat concept for commercial buildings (the electrical firm Crompton Parkinson is also working in this field). A multi-disciplinary team is studying the subjective comfort in relation to refined measurement of environmental conditions. There is also work to improve unit storage heating devices, developed at the Electrical Research Association laboratory. The former Ministry of Power (now Ministry of Technology) encouraged the nationalised fuel industries to set up a research liaison committee. Promising fields for collaboration among fuel industries include the development of those parts of heating systems which are independent of the primary heat source, such as district heating; but the gas and

electricity industries are likely to remain strongly attached to dispersed heating systems which exploit the ease of distribution of their products compared with coal and oil. CRAC did not think, however, that even with greater collaboration, research based on the fuel industries could fully meet the needs of services engineers and their clients for design data and systems adapted to building requirements.

8 Engineering Equipment Manufacturers

Manufacturers' research has been dominated by market considerations. The United Kingdom manufacturers have concentrated on the small heating installation market which has grown enormously during the past decade. Progress has been made with boilers, pumps, convectors, radiators, classroom heaters, electric storage heaters. Demands of larger builders have caused progress with light fittings, gas heaters, radiant panels, heated ceilings, air-handling equipment. Innovation has often evolved from co-operative research on manufacturers' behalf at research associations, e.g. small bore systems (BCURA) and mini-bore (HVRA). Air-conditioning, and to a lesser extent automatic controls, have been dominated by American companies who, though usually manufacturing in the United Kingdom, have been served by American research. Having regard to the vastly greater market influenced by population, climatic conditions, and standard of living, it is perhaps inevitable that research in this field in the United Kingdom has played a secondary role. There is, however, work to be done and room for original thought in translating American practice to the United Kingdom environment. Examples of what can be done may be seen in Sweden and Switzerland.

B The Public Sector

9 Building Research Station

Environmental design has a long tradition at BRS, and other centres which study it in this country often include people who have worked at BRS. The Environmental Design and Engineering Division continues to be the largest group on the subject, with 60 staff, and it is supported by the Information Division in disseminating results. In view of the Station's decision to make environmental design and engineering one of the priority areas for growth, it may expand relatively fast in the next few years. BRS is likely to remain the largest centre for environmental engineering research in the foreseeable future. The Station places particular emphasis on subjects of interest to Government, on those requiring large resources and many disciplines, and on those aspects of building services which are closely bound up with the building as a whole. Among developing programmes in environmental design are studies on sound insulation and on the environmental requirements in deep buildings; engineering services programmes now building up concern refuse disposal systems and the standardisation of some of the simpler ventilation and waste systems. BRS brings to its projects relatively large resources and a multi-disciplinary approach. The main beneficiaries are the design professions, and BRS has given considerable attention to improving its communications to them by means which include the provision of data in a convenient form and running courses and seminars. BRS policy is to concentrate on a limited number of projects lasting not more than three years, rather than attempt to cover the whole field. This policy not only makes for effective research, by defining the Station's current interests it also helps others to identify the fields where their contribution will be most useful. The demarcation with the HVRA is complex but reasonably clear, and there are good relations between the two bodies.

THE HEATING AND VENTILATING RESEARCH ASSOCIATION

10 The HVRA, which receives a grant-in-aid from the Ministry of Technology, has about 50 staff. It represents a wide range of interests in the design and installation of heating and ventilating services, including manufacturers, contractors and consultants. It bases its plans on widening the field it covers, in line with a trend in the industry, to include electrical and plumbing installation, and on offering a greater range of services to members. By developing its testing work (which has increased in two years from £9000 to £28,000), by obtaining two large contracts, and by some increase in membership, it has raised its income from £70,000 in 1967 to £125,000, and it has a measure of financial stability. The programme includes work to refine air-conditioning design data, a long-term study to provide data on the reliability and maintenance of a plant, measurement of the thermal characteristics of district heating systems, a survey of computer programs and assessment of designers' needs in this field, and studies of procedures for installation, design and contract management. Dissemination activities include the information service (3000 enquiries in 1968), abstracts and other technical notes, participation in standards committees, and one-day courses. Being a co-operative agency of the industry, HVRA is the best placed of the bodies examined here to put its research across directly to industry. It is less able than BRS or universities to tackle multi-disciplinary design problems (in which contractors and manufacturers are less interested) or to influence the training of recruits. CRAC sees considerable potential for growth of the association in those topics which are of interest to its membership, and hopes that it can double the size of its research organisation. To do this, it will need additional Government contracts, since further growth of membership can only follow a broadening of the association's field and services. MPBW has already placed some contracts and is discussing others with the HVRA.

11 Electrical Research Association

The Electrical Research Association has a number of projects relevant to building services, including work in support of regulations, tests of novel installations and methods, and research into connections for aluminium wiring, and it has a tradition of research on internal environments. Its work has included development and investigation of various electric heating methods, notably floor warming and thermal storage, and studies in related topics like the thermal behaviour of buildings, methods of heat distribution, and heating controls. It is currently interested in warm air heating, mixed heating systems, improvements and wider exploitation of storage heating, and thermostatic control. The extent of the programme of environmental research will be determined by the financial support it can obtain from sponsors, since unlike other research associations it no longer finances research from subscriptions, matched by grant-in-aid. The Ministry of Technology grants are identified with particular projects for which groups of members are prepared to pay.

12 Universities and Colleges

The number of universities interested in construction studies is large, and it includes:

Scotland (Glasgow and Strathclyde)
North East (Newcastle)
North West (Liverpool, Manchester with UMIST, Salford)
Yorkshire (Sheffield)

East Midlands (Nottingham and Loughborough)
West Midlands (Aston)
South West (Bath and Bristol)
London (University, and National College, part of South Bank Polytechnic).

Those with the longest established research groups are Glasgow, Newcastle, Liverpool, and University College. Others whose long-established groups have touched on environmental design are Strathclyde and Manchester. The National College has a small programme of work on services. Inter-disciplinary groups at Nottingham and Bristol have recently received SRC grants and other financial support. None of these groups has more than a handful of qualified full-time staff.

There is a growing number of undergraduate and postgraduate courses of varying scope available at teaching centres throughout the country.

While welcoming this evidence of universities' increasing interest in a neglected subject, and the way that other disciplines are turning to building services problems (for example, mining engineering at Strathclyde and Nottingham, aeronautical engineering at Bristol, ergonomics at Loughborough), the Council's impression was that both research and teaching suffer from a proliferation of initiatives. At the present stage of development the courses at undergraduate level do not attract students of high average quality, the numbers at this and at post-graduate level are small, and the few experienced teachers are scattered among a growing number of universities interested in building education.

13 Other Bodies

Apart from the bodies already mentioned, many others have scientific experience and equipment which could assist in certain lines of study in this field. Examples which came to notice were:

Atomic Energy Authority	—work and equipment in connection with aspects of power station construction
National Engineering Laboratory	—fan-testing and fluid-flow research equipment
National Physical Laboratory	—work on acoustics and metal corrosion, equipment for aerodynamic tests
Royal Aircraft Establishment	—work on specialised environmental problems
Hydromechanics Research Association	—equipment
Greater London Council	—Scientific Branch has worked on various services and on integrated thermal design.

Except where, as in the GLC case, the work is immediately used by a design office, the resources of these bodies tend to be used for work in this field of interest either spasmodically, when somebody with a problem gets to know that they can help, or in association with a body which has closer ties with the construction industry. For example, in some scientific studies the NEL collaborates with the universities at Glasgow.

EXPANSION OF RESEARCH

14 The expansion that CRAC recommended cannot be achieved at any one centre. The Council welcomed the intention to give this field a high priority in BRS's future growth plans. It recommended that Government departments should assist by means of contracts the HVRA's programme for extending its range and activities. To put university work in this field on a firmer base it recommended that a research institute should be set up with a grant-in-aid from the Ministry of Public Building and Works, and that Government departments should progressively concentrate their support for research in this field at a small number of other universities, since the human resources for both research and education related to services engineering are scattered among too many small centres.

15 There is wide agreement on this diagnosis of the research situation, and it is evident that only a positive policy on the part of the Government departments mainly concerned —SRC, MPBW, and others with building programmes which let research contracts— can bring about concentration. Through their representatives on CRAC they have concurred in the proposal to set up a research institute in Glasgow where there already exists a Building Services Research Unit in the Mechanical Engineering Department of Glasgow University, and relevant work in the Departments of Architecture and Building Science and Mining Engineering in Strathclyde University. The institute would aim to grow quickly to a staff of 60, half of whom should have appropriate professional or degree qualifications. It would develop close relations both with adjacent universities —who would remain responsible for teaching—and with industry and design offices, both engineering and architectural. Its approach would be multi-disciplinary, looking at services and the internal environment in relation to the building as a whole, and at solutions from the point of view of the design team.

16 Funds to support the proposed institute during its early years can be made available by MPBW. The details of the institute, including the programme of work, will have to be worked out in negotiation with interested parties—including BRS and HVRA. But there are two important factors in CRAC's decision which have a bearing on the institute's programme. First, it will be uniquely qualified by its university setting to develop mid-career courses and seminars and to give an indirect boost to the education of new entrants to services engineering by raising the status of the subject. Secondly, the major centres of research in this subject are around London, so the institute (although it is intended to have national standing) will be well placed to develop contacts with firms and design offices in Scotland and northern England.

17 The SRC policy is to support the development of stronger continuing centres of research, while remaining ready, within this general policy of concentration, to consider able people with good ideas at other universities. CRAC recognises that there will be particular subjects for which the resources of one university may be especially appropriate, and that absolute concentration of all environmental engineering research in one or even two universities would close avenues for further development. CRAC recommended that MPBW should limit its support to one or two centres: the Ministry will ensure by liaison with SRC and other sponsoring bodies that this leaves open the possibility of support for valuable work elsewhere. CRAC considered that the long-established group in the Building Science Department at Liverpool had a special claim to continued support. The National College of Heating, Ventilating, Refrigeration and Fan Engineering,

as a major centre of education for services engineers, should be encouraged to do some research. CRAC did not attempt to decide which other universities should continue to work in this field. Since they draw support from a number of sources, including industry, the process of concentration will be essentially evolutionary.

OTHER CENTRES OF RESEARCH

18 CRAC did not overlook the substantial programme of research in laboratories associated with the coal, gas, electrical and oil industries and in firms manufacturing equipment. Commercially-oriented work in these laboratories is probably the largest influence for change (which is not always the same as progress) in this aspect of construction. But the client expects his professional adviser to offer the most economical design solution, in capital and running costs, that satisfies the requirements. This must be based on information that is not biased towards particular fuels or brands of equipment. The laboratories of the fuel and equipment industries can contribute here. Many developments, such as district heating, are in principle adaptable to various fuels, while others, like heat-with-light, are total approaches which are unlikely to be adopted without careful evaluation. But for the building designer to take advantage of the developments and investigations of these laboratories their work must be compared and evaluated by organisations qualified to provide an impartial view.

19 CRAC's main concern is with these organisations. The Council takes the view that once a pattern of construction-oriented environmental engineering research is established, related work based on suppliers of fuel and engineering equipment falls into its proper place in the picture.

APPENDIX 4

Research and Development Needs in Construction Materials and Components

(Based on a note by the Directorate of Research and Information, MPBW, September 1968)

Research Needs

1.1 Materials and components account for about half the cost of construction and attract some two-thirds of the total research and development effort. A survey undertaken by the MPBW for 1966 showed that in the sector supported by public funds some £1 million was spent on materials research and development and related studies in design and production. In the private sector, expenditure on materials research and development is difficult to assess, but was not less than £6 million by manufacturers and their trade associations and around £250,000 by contractors.

1.2 An analysis of the effort in the sector supported by public funds shows that the major effort was on the general properties of materials, the assessment of performance and its improvement. These studies accounted both for more than half the total effort and that of each organisational group. There was little expenditure on studies of performance needs and specification or on environmental forces. In addition a further £600,000 was spent on research and development studies of the structural behaviour of brick, concrete, metal, timber and plastics components and structures, £56,000 on materials handling and £29,000 on economic studies. Expenditure by manufacturers and their trade associations was mainly on improved manufacturing techniques or on the development of new or improved components.

1.3 It can be seen from the foregoing that the expenditure by manufacturers is dominant; much of it is directed towards innovation in materials and components. Though such innovation contributes to an increase in productivity through consequent changes in construction techniques, competitive pressures can lead to excessive variety insufficiently related to the needs of the user. Some control on innovation is thus desirable both to offer a guide for the inventiveness of industry and to afford user protection. This guidance can be exercised through the introduction of performance standards and is seen to be a primary concern of the Government sector chiefly through its Development Groups drawing on the work of the research stations. The testing and certification of the probable conformity of new products to these standards is the responsibility of the Agrément Board as an interim stage before their final introduction into national standards by the British Standards Institution.

1.4 Such guidance to industry must be progressive and imaginative and should be based soundly on specific needs objectively stated. To prevent restriction deriving from ignorance these needs must be based on knowledge of the conditions which a material or component has to withstand and the mechanism of the changes which take place over its life. They must be consciously related to the processes of design and construction and their cost, for it should be borne in mind that most existing materials perform reasonably well and most are very cheap. To test the relevance of performance standards greatly improved feed-back from sites during construction, and from maintenance groups when the building comes into use, are needed.

2.1 To support the interest of users in the quality and fitness for purpose and performance of materials and components, research and development is needed in the public sector to determine the general and basic properties of materials, their behaviour in practice and to predict probable performance. This follows the pattern of the past but is still valid today since industrialisation and rationalisation in the design of buildings and components and in erection techniques give rise to problems of maintenance of

materials and components different from those already understood. Furthermore, new components are being marketed in increasing quantity with little basis in tradition for prediction of their behaviour and traditional materials are being used in new situations which make it unlikely that the effects of environment upon them will be as before. Research and development are essential to provide meaningful performance specifications to meet these demands.

2.2 Areas of research and development are not in practice detached from one another but it is a convenience in this paper to separate them as follows. They relate both to the public and private sectors of the industry.

(a) Environmental forces.
(b) General properties.
(c) Performance in use.
(d) Development of new or improved materials and components.

2.3 There is a need, too, for economic studies of materials and components but these are seen best as part of the general area of economic research needs which is the subject of a separate review by the Council.

3.1 **Environmental forces.** Despite the research undertaken in the past there is a surprising lack of detailed understanding of the forces—mechanical, physical and chemical—to which materials and components are subjected in practice. These are known broadly but insufficiently to a depth which permits the true understanding of their effects to be calculated and, eventually, remedied. For example, while the reasons for, and magnitude of, overall movements of components are known, there is so far little knowledge of the pattern of movement and the stress/time relationships involved. Such knowledge is necessary, *inter alia,* for the logical development of joint sealing materials. Research and development projects in this area include:

(a) The nature, pattern and magnitude of movement in buildings, components and materials.
(b) Measurement of stresses in and on components and materials.
(c) Measurement of macro- and micro-climate in varying geographical areas of the United Kingdom.
(d) Development of instruments to determine (a), (b) and (c) above.
(e) Determination of ambient atmospheric conditions within spaces, particularly roof spaces and under suspended floors.
(f) Determination of the chemical nature of dirt including chimney effluents.

3.2 **General properties.** The performance actually obtained from a material or component will depend not only upon the dynamic forces—often climatic though not necessarily so—to which it is subjected in practice, but also upon its intrinsic properties. These need to be understood at a molecular level if prediction of performance is to be soundly based and before new materials with improved properties can be systematically evolved. Much research on general materials properties and their modification has

already been undertaken and will be a continuing area of work. It is believed, however, that a particular need is at a more basic level. The main area for study here includes:

(a) The relationship of the pore structure of porous solids to moisture migration and its effect on wetting, frost damage, efflorescence, salt attack, and moisture movement.
(b) Crack propagation in brittle solids and its control.
(c) Effect of cyclic stressing on strength.
(d) Bond strength between materials and the effect of surface films.
(e) Creep of stressed materials, particularly polymers and composite materials.
(f) General rheology of materials, particularly flow properties, self-healing effects and workability.
(g) Relationships of shape, weight, density, and impact strength to ease of handling.

3.3 **Performance in use.** The performance of materials in construction—mainly of durability—has been extensively studied for many years but the final result has been less profitable than it might. In general, observations have been mainly qualitative and often unsystematic and communication between the skilled observer and those most likely to benefit from his knowledge has been inadequate. A firm statistical basis to the conclusions has often been lacking.

3.4 There is a need for systematic observations of materials, statistically planned, quantified wherever possible and fully supported photographically, of the physical state including appearance and its change with time. Such observations when related to external durability are needed to show the effect of major climatic differences within the United Kingdom, e.g. coastal, rural, and urban areas, areas of high rainfall and cloud, areas of low rainfall and maximum solar radiation. Such observations could well be started in new buildings in which the actual construction is followed, which could be instrumented and to which the necessary access could be obtained: government buildings are an obvious source.

Projects may be defined within the following areas:

(a) development of scales of performance, particularly of deterioration, and of test methods based on practical usage;
(b) statistics of performance in relation to age;
(c) relationship of design detailing to change of appearance with time;
(d) rate of dirt deposition and build-up and the mechanism of its retention and removal;
(e) protective value of dirt;
(f) determination of the physical state of materials in use by non-destructive methods;
(g) development of instruments for (f) above;
(h) acoustic properties of lightweight composites;
(i) effect of moisture gradients on thermal insulation of components;
(j) determination of transient heat flow through components, the effects on it of moisture and the relative significance of thermal capacity and insulation;

(k) development of extrapolation techniques of prediction based on physical change under natural conditions;

(l) determination of the rate of change of moisture content and temperature of materials.

3.5 **Development of new or improved materials and components.** Any gap between actual or predicted performance of materials on the one hand and required performance on the other will point to the need for development of new materials or components. It is believed that the climate of change now surrounding the construction industry points to the need for a more conscious and objective search for ways of altering properties of existing materials or developing new ones, but this should not be considered solely in terms of properties and performance when in place in a building. It is now very apparent that materials must not only be capable of being mass-manufactured but must be handled, installed, and maintained readily. Materials development should be undertaken with a production/installation/maintenance relationship constantly in mind. It is believed that this relationship has, in general, been inadequately studied.

Some relevant projects within this area are believed to be:

(a) development of inorganic insulants;

(b) development of rigid, lightweight components;

(c) evaluation of the relative merits of medium density and low density materials;

(d) effects of alternating high and low density foams in composite panels;

(e) properties of laminates and effect of core material on buckling restraint;

(f) development of pumped gap-sealers;

(g) development of waterproof insulators;

(h) development of non-dirtying surface films;

(i) development of jointing materials;

(j) development of fibrous reinforcements;

(k) development of fire-resistant plastics;

(l) identification and modification of those material properties inhibiting productivity in manufacture and construction;

(m) determination of manufacturing tolerances in shape and dimensions.

4.1 **Economic justification.** It should again be stressed that the financial margin for successful innovation in construction materials is small. Most materials are almost literally 'dirt-cheap' and their performance is reasonable. Research and development cannot effect major cost reduction in a material when performance remains constant, neither is it likely to greatly improve performance at a constant price. However, of the £4000 million of gross output of the industry about a half is the value of materials and components and a third is spent on maintenance. The effective value of this expenditure can be directly increased by research into materials and components. Also, the development of materials' properties can lead to radical design changes with indirect savings through the better utilisation of space, for example, the development of prestressed concrete allowed greater spans to be achieved with less intermediate support.

4.2 Cost-benefit analyses may in certain cases be applied to specific developments but not to the totality of research and development within a major area, which is the form of this paper. However, some benefits already assessed from past projects may serve as examples to support the general case for research and development in this area. For example, work done by BRS on grading of sands for concreting has allowed better use of available deposits and is estimated to have saved over £200,000 a year. It is reasonable to believe that development of indigenous materials as alternatives to timber, e.g. fibre-reinforced plaster, would result in a substantial reduction in our import bill. Again, an earlier knowledge of the likely behaviour of Anston stone could have saved the Houses of Parliament from unsuitable restoration costing more than £1 million. When the Anston stone had to be replaced, scientific research into the respective properties of Clipsham stone and Darley Dale sandstone led to the correct choice of the former and undoubtedly prevented a further similar heavy expenditure from being incurred. Many current examples can be given of failures deriving from inadequate technology based on research and development. The lack of fully satisfactory jointing techniques for certain wall and large-panel construction used in much of the public building programme will result in heavy maintenance expenditure in the future and intensive research to solve this problem is urgently required.

Functions of Organisations

5.1 **Government research stations and departments.** In the sector of the industry supported by public funds Government research stations are responsible for the bulk of research and development on materials—around £750,000 in 1966. The multi-disciplinary nature of Government laboratories and the considerable background knowledge acquired over long periods—nearly 50 years in the case of the Building Research Station, the major laboratory concerned—fit them generally to tackle most of the research and development needs suggested. Their primary responsibility is seen as providing the basic research structure upon which the evolution of performance standards must depend. Such research involves studies of environmental forces, of general materials properties and of performance in use and its prediction. End products of such research include the development of test methods and the drafting of performance specifications. The work done provides the basic data for many organisations but notably for CIRIA, the Agrément Board, Building Development Groups, the Component Co-ordination Group, MHLG and the British Standards Institution.

5.2 A further main responsibility of Government research stations is to undertake economic and technical studies of materials costs and resources with particular regard to the conservation of natural resources, the effective use of waste materials and the reduction of non-essential imports.

5.3 The Development Groups in Government departments are actively engaged in preparing performance specifications for components which can serve as a basis for tenders for components used in the associated building programmes. The Interdepartmental Component Co-ordination Group is responsible for the general co-ordination of all separate approaches and has primary interest in the development of ranges of compatible dimensions for components.

5.4 The development of performance standards, the determination of performance in use and the innovation of materials and components imply the need to check performance

against specification through standard tests and quality control. Standard and quality control testing is mainly undertaken by the British Standards Institution and by large building organisations and any move to the formation of larger local authorities might encourage such testing following the pattern of the Scientific Advisers branch of the GLC. Commercial testing houses already exist to undertake tests on repayment. The MPBW has a special interest in testing both through its Maintenance Committee and through its responsibilities for the Agrément Board. The research associations, too, wish to be considered as testing centres for their industries and some Colleges of Technology already operate testing services and hope to develop them.

5.5 It is evident that existing arrangements for research and development in support of the consumer interest in construction materials and components are inadequate. The Ministry has decided, on CRAC's advice, to set up a scientific organisation based on the Agrément Board to develop methods of assessing and testing in support of the introduction of performance standards, and thus to provide scientific backing for the work of BSI, development groups concerned with component co-ordination, the Agrément function, etc.

6.1 **Universities and colleges of technology.** The interest shown by universities and colleges of technology in building materials technology is small, only amounting to some 5 per cent of their total research effort in construction. Departments of Civil Engineering accounted for most projects reported in 1966. Some research into materials is of a fairly basic nature, for example, that on silicate chemistry, rheology, pore structure and polymers. This is seen as particularly suited to university study posing as it does problems at an intellectual level sufficient to justify the employment of higher quality post-graduate workers. There is a need to attract the interest of a small number of Departments of Chemistry or Materials Science in the special problems of construction. This interest may best be stimulated through the creation of small research units and the continued support of existing activities. Particular interest has been shown by the Universities of Bristol and Surrey, and Queen Mary's College, London.

6.2 It is believed that universities can also play a part in studies of the environmental forces to which materials are subjected in practice and the resulting performance, particularly in view of their geographical dispersion. As such research usually requires persistent systematic effort which may often prove unrewarding it is necessary to avoid a diffuse approach and to concentrate on specific narrow-based and short-term studies. Some 40 universities and colleges are associated with BRS in a programme of observations on the performance of materials *in situ.*

7.1 **Grant-aided research associations.** It has already been shown that research and development needs in materials can no longer be considered in isolation from the construction process as a whole. However, the fact remains that manufacturing industry and construction industry are still essentially distinct (though the setting-up of building development groups within some manufacturers is a welcome move). The research associations occupy something of a key position in bridging this division, particularly following the formation of CIRIA. A focal point for consideration of building materials problems in the RA's is afforded by the Building Materials Working Party of the Committee of Directors of Research Associations (CDRA).

7.2 Research and development by the grant-aided research associations into building materials and related work in 1966 was estimated as being around £200,000—about

one-third of their total research for construction. This effort on materials research and development, it is believed, is far too small in relation to the key role that the research associations could and should perform, and there is scope for the research associations to extend their research and development in relation to construction, on the development of new uses of their materials to meet specific needs of construction and on OR and production engineering studies related to the cost and efficiency of the service their industry provides to the construction industry. It must be accepted that in some cases it may well be unreasonable to expect financial support for such research from industry and that earmarked grants from Government will be necessary.

7.3 Many of the research associations deal with materials which have application in other industries besides building. The dispersion of materials between many research associations and the fact that a material within the province of one may be a competitor to one within another are obstacles to co-ordinated research effort. As already noted, however, co-operation exists to a degree through the Building Materials Working Party. There is clearly scope for its advance in the development of test methods for evaluating the performance of materials and components, in instrumentation for measuring general properties, in the development of materials and components (particularly composites) and in studies relating to production and handling techniques, and it is proposed to follow-up earlier discussions with the Working Party to identify suitable projects.

8.1 **Private industry.** Private industry is responsible for more than 80 per cent of all research and development on building materials. Much is competitive and not freely available. It is the manufacturer of materials who is nearly always responsible for innovation of materials in the construction industry—seldom the contractor. The manufacturer often has great difficulty in this. The contractor has no incentive to use a new material unless he saves labour; the architect has no financial incentive—the reverse if the material is cheaper—and takes a risk to his reputation if failure occurs. Only the client may gain and he may be disinterested or too inexpert to assess what this might be. Moreover, for what may be modest saving in initial cost or unquantifiable improvements in quality he is often unwilling to take the risk of failure.

8.2 For a manufacturer to undertake development of a new material or component he must expect to secure an adequate market share and be reasonably certain that final market price will be competitive with existing similar materials. Having done this successfully he may only enjoy a competitive edge for a relatively brief period. If a proper analysis of cost and return were made it might well be shown that the second in the field was often in the optimum position. If development of new materials and components is to proceed at a rate appropriate to the national interest it is unlikely to be sufficient for official involvement to stop at the establishment of performance standards. Support through purchasing policy will be provided, for example, as part of the programme of component development by Building Development Groups, but the commissioning of the development of specific materials or components may also be justified on occasion.

Conclusions

9.1 In considering the arrangements for this work it must be born in mind that there will be overlaps between organisations, for seldom can research and development needs be seen as exclusively the province of one type of organisation.

9.2 Finally, it is worth stating that, while design has an influence on the performance of materials, their properties have a less obvious but major effect on design. Development of materials could lead not only to improved performance, but to radical design changes; materials are the cornerstone of design.

9.3 The Council:

(a) noted the main areas requiring further research and development in the field of materials and components;

(b) endorsed the conclusion that Government research should be primarily directed towards an understanding of the environmental forces to which a material is subjected and the mechanism of change and so provide a research base essential to the adequate functioning of standards, advisory and testing services; agreed that base required reinforcement; and approved proposals for a scientific organisation (CITAS—Construction Industry Testing and Assessment Service) based on the Agrément Board;

(c) endorsed the proposal to establish a limited number of research units at selected universities for studies of basic materials properties;

(d) agreed that research aid should be given to research associations through earmarked grants by Government for specific development, and that there should be discussions with the CDRA Working Party on Building Materials on possible collaborative developments;

(e) accepted that support for development by individual firms of materials and components might be given by Government.

APPENDIX 5

Construction Economics Research

(Based on a note by the Directorate of Research and Information, MPBW, January 1969)

1 This paper briefly describes the current activity on construction economics, using the 1966 Survey of Construction Research and Development as a base, supplemented by information from other sources. The paper goes on to suggest aspects on construction economics in need of further research. It concludes with a suggested organisational framework for the research required.

2 Construction has not enjoyed the distinctive treatment accorded to agriculture, which has the advantage of well-endowed Departments of Agricultural Economics in the universities, although its claims may seem to be as great. Nor has it attracted its share of the growth of interest in economics applied to public policy formation of recent years. Indeed there has been, if anything, some loss of interest of some of the more senior economists who were interested in construction until a year or two ago. There is now among the Departments of Economics none which has a major interest in construction.

3 It is necessary for this paper to take a reasonably precise definition of the subject area, excluding subjects such as operational research, management, human factors research, etc. The analysis below of research current in 1966 has thus been confined to sections EC1, 2 and 9 of the survey (with some amendment).

	£000's		
	Universities	Research Stations and Associations	Total
EC1 : Construction, Demolition, Constructional Materials and Services	10·0	34·8	44·8
EC2 : Maintenance and Running Costs	1·2	—	1·2
EC9 : Structure of Industry	7·6	44·0	51·6
	18·8	78·8	97·6

4 To this analysis must be added the information from more recent enquiries and the projects undertaken in the industry. In neither case is it possible to distinguish the cost of projects, so that the figures cannot be included in the analysis above.

5 A convenient distinction may be made between:

A. Studies of macro-economics of the functioning of the industry as such.
B. Micro-economic studies of the functioning of individual firms or projects.
C. Research into the economics of the construction product.

A Macro-economics of the industry

6 The central problems relate to the demand on the industry and the capacity of the industry to meet this demand (at given or prevailing prices), depending both on the supply of resources, including labour and materials, and an appropriate structure of industry.

7 The demand for construction, while showing some sensitivity to changes in prices, depends largely on external factors such as changes in the economy as a whole, population growth, etc. Models have been developed to predict demand for certain sectors, notably house construction and forecasts for long-term housing demands have been made by Dr Peter Stone and others. The NEDO provide forecasts of public sector demand but more information is needed on the private sector, especially on the factors influencing the investment decisions of industrialists.

8 A more comprehensive approach to the demands on the construction industry as a whole is by means of input-output models of the type developed by Prof J R N Stone at Cambridge. The BRS has done some work on input-output models for the construction industry as a contribution to the Cambridge model but, on the advice of its Econometric Committee, has recently turned its attention to the derivation of the functional relationships on which the model is based rather than to making the model more detailed and comprehensive.

9 It is accepted doctrine that the characteristics of demand are critical factors affecting the structure of the construction industry and the efficiency of its processes. Some evidence suggests that benefits may be secured through the operation of consortia, but it can be argued that long-term guaranteed markets would tend to increase price levels generally. The subject needs critical examination so that the influence of the various aspects of demand can be better understood as a basis for policy.

10 Long-term forecasts are inevitably speculative and there is a good deal of interest, especially in industry, in short-term forecasts, and in the regional analysis of both short and long-term forecasts.

11 There are a number in operation on different bases, mainly making use of statistics of work flowing through early stages of the process to predict flow at later stages. A study in depth of the relationship between planning decisions and construction statistics has been suggested and could provide results of great interest. A recent innovation has been the attempt of market research agencies to provide a forecasting basis, allowing for trends in design. Studies at University College, London, sponsored by MPBW, aim to provide an improved model of the timetable of the building process and may enable the reliability of these forecasts to be evaluated and improved.

12 The supply of labour to construction is variable both in its character, in terms of skill, and its regional distribution. It is closely related in certain areas to other industries which offer alternative employment. The supply of labour is particularly important in influencing the rate of developing of new towns, for example, and, at times of a high level of demand, in enforcing new technological solutions in the industry. Recent studies for the NJC by BRS and work of the Phelps Brown Committee have thrown some light on this subject and CITB have convened a Working Group, on which the Ministry are represented, to develop a collective approach to a 'model' for the demand for labour for the industry.

13 The supply of materials for construction is characterised by the classical 'hunting' phenomenon by which crises of shortages and over-capacity alternate regularly. The cause of the material shortages may often be anticipatory ordering which might be obviated by suitable measures such as bigger stocks, or on providing more information

on the future availability of materials. There is a need for further knowledge of the mechanism of materials supply which would take account of the costs of stock holding at various parts of the system. This should include a study of transport costs in affecting decisions on the use of building materials. Such a study would also provide information relevant to the study of the economics which might derive from the concentration of production facilities, say of particular components, in a few large manufacturing units.

14 The factors conditioning the capacity of the industry to meet demand are little understood. And although some indicators of a state of overload on the industry are easily recognised, the influence of overload on the productivity of the industry and on the level of prices is a matter of controversy. This is clearly a question of great significance for central Government.

15 The headings for research suggested above are as follows:

(a) The study of the structure of the industry.
(b) An investigation into the possible effects of long-term commitments by the public sector on prices, wages and productivity.
(c) The determinants of demand.
(d) Input-output models for construction in relation to the economy as a whole.
(e) Long-term, short-term, and regional forecasts of demand.
(f) Timetable of the building process.
(g) Distribution and movement of manpower.
(h) Mechanism for ordering, stock holding and distribution of materials.
(i) Influence of transport costs on building decisions.
(j) Factors conditioning the capacity of the industry; the relationship between demand and capacity with particular reference to the definition and effects of overloading and underloading.

B Micro-economic studies of individual firms and processes

16 The efficiency of the industry depends ultimately on that of its component parts, the designers and contractors who carry out the work. There is evidence that the performance of individual firms in the industry is highly variable. A study of productivity in house-building in the early 1950's showed the man-hours per house of the least efficient firm to be three times as great as that of the most efficient and there is more recent though less complete evidence to suggest that the gap may now be wider. The RIBA study of the Architect and his Office indicated a similar range of performance among architects.

17. Classical economic theory would suggest that, at least among contractors, the more efficient firms would grow at the expense of the less efficient, but while there is some evidence of this mechanism in construction, it is confused by the influence of many other forces, the effects of which are imperfectly understood. There is a need for a better understanding of the factors which influence the growth and efficiency of building firms and the relative significance of security of capital, management, and manpower. The restraints imposed by the demand for working capital which can arise from the stage payment system need to be seen in the light of the methods of financing firms

in the industry. A related problem is the low rate of capital investment of building firms which may be a factor restricting the degree of mechanisation.

18 The marketing and pricing policies of building firms is a subject of great current interest in the industry as well as academically. It is evidently vital for the understanding of the strategy by which firms maintain a continuous employment of their resources.

19 A comparison between building firms is made by Inter-Firm Comparisons and, following the initiative of the NEDC and CITB, the number of firms co-operating in the exchange has increased recently. The interpretation to be given to the individual ratios was recognised by the NEDC as calling for additional research. Such research would need to take account of other factors influencing efficiency, such as the management structure, the degree of specialisation and geographical concentration of activities in relation to size. The last factor is associated with questions of the regional organisation of firms and the distribution of functions between head office, local office, and site, which are of considerable economic interest.

20 Some work has been done on the economics of particular techniques such as the evaluation of incentives and mechanisation but this requires up-dating to take account of changes in the industry and the economic balance between the employment of machinery and manpower.

21 It is now nearly 20 years since the last comprehensive survey of labour productivity in house building mentioned above. Such a survey would today present more difficulties because of the greater variety of the building product, but an enquiry into the definition and methods of measurement of productivity in construction would be valuable either as a precursor to such a survey or to provide alternative measures, based perhaps on available statistics.

22 The efficiency of individual operations on site may best be considered as operational research and is not treated in this paper.

23 The headings for research suggested above are as follows:

(a) Factors influencing efficiency and growth in individual firms.
(b) Financing of firms in the construction industry.
(c) Marketing and pricing policies.
(d) Significance of inter-firm comparisons.
(e) Evaluation and guides to decision taking on incentives, mechanisation, etc.
(f) Methods of measurement of productivity.

C Economics of the construction product

24 By construction product is understood the whole of the buildings, civil engineering works, and maintenance which collectively comprise the output of the industry. Expenditure on new works alone accounts for half the annual fixed investment in this country. The construction product has a long life compared with other forms of investment and so buildings represent a high proportion of our stock of capital. Decisions on the provision of new buildings thus have a major economic significance both nationally and to individual organisations and persons, and there is a need for a better understanding of the

principles which should govern them. The problem posed by the longevity of buildings is accentuated by the increasingly rapid rate of change of the user need for buildings, in terms of space and functional standards, operating conditions, influence of car usage, etc., as well as the continued inflationary tendencies. Better information on the stock of buildings and of factors inducing obsolescence would contribute to the development of a strategy for dealing with national problems as well as those of large organisations. Further studies of the evaluation of the provision of flexibility of use by various means would also make a valuable contribution.

25 For individual buildings, 'cost in use' methods have been developed to provide a basis for designers to take account of running costs as well as the initial capital cost. The basic methodology is fairly simple but there remain obstacles to the effective use of the method deriving from the uncertainty attaching to the expected life and cost data for maintenance, as well as the problems of the choice of discounting rate.

26 The quality of the basic data is also central to the use of cost-planning methods by which the designer is guided as to the likely capital cost implications of his design decisions. The data normally derive initially from builders' priced bills of quantities and are thus subject to variability and soon become outdated. A method is required which is less sensitive to variations in price data but which reflects time trends in prices. The RICS has established a cost information service for quantity surveyors and it would seem possible that a further stage might be the development of a building cost-data bank, providing data for use in cost planning.

27 An efficient cost planning method is a prerequisite for the effective operation of cost limits. The use of such cost limits by Government at times of rising price levels is said to drive designers to lower quality, so increasing the cost-in-use of their buildings and although there is little systematic evidence that this is the case, a reliable price index would be of the greatest value for both cost planning and cost limits. It would permit the up-dating of historical price data to provide a basis for feedback as well as providing a basis for the adjustment of cost limits. Research on construction price indices at UCL jointly supported by RICS and MPBW, is nearing its conclusion and should offer a satisfactory basis for action, but there remains a need for research on the operation of cost limits.

28 Studies of the prices of complete buildings may be made by reference to the detailed analysis of bills of quantities for individual buildings (termed 'cost analysis') or by statistical analysis of the total tender price of a large number of schemes. Cost analysis draws heavily on the expertise of the quantity surveyor and relies on his background of experience in interpreting the results, but there may be scope for research in improving the methods so employed, and for improvements in the supply of basic data. Statistical analysis has been employed in studies of the prices of local authority housing, enabling the effect of number of storeys, size of dwelling, region, and size of scheme to be identified. Such studies have been extended fruitfully to compare different forms of domestic accommodation such as housing, student hostels and nurses' homes. There is scope for extension of these enquiries to other building types as well as up-dating of past work relating to housing.

29 Cost-planning techniques require access to historical cost data relating to similar buildings. When the designer wishes to evaluate a new form of construction a different

technique is required. This problem arises particularly in system building, for example, when a decision to invest substantial sums has to be taken before a full-scale trial can be undertaken. Some attempt has been made to apply simulation techniques to the problem of decision-taking under these conditions but a good deal more development is required before they can be considered as suitable for use in industry.

30 The control of the cost of a building in the interest of the client is normally exercised by the quantity surveyor through the mechanism of the bill of quantities. The bill of quantities has many defects as such and has been shown to be insensitive, in reflecting variations in actual costs and inefficient, in requiring much information irrelevant to the determination of the tender price. There have been a number of developments aimed at improvement of the bill of quantities in recent years but there is a need for a more fundamental study of the operation of the bill to provide a more rational basis for its improvement. Closely related to this subject is the problem of cost control during construction exercised by the contractor, which should be able to be related to the bill of quantities descriptions, so offering scope for a closer relationship between prices and costs.

31 The headings for research suggested above are as follows:

(a) Policy for investment in construction nationally and in individual organisations.
(b) Building stock and obsolescence, cost benefit analysis of flexibility.
(c) Problems of cost-in-use—the 'trade off' between expenditure on capital costs and running costs.
(d) The comparative study of the cost of buildings.
(e) Economics of different design solutions.
(f) Economics of scale in the production of (i) components and (ii) buildings.
(g) Evaluation of techniques of cost limits and cost planning.
(h) Indices of movement of building prices.
(i) A building cost data bank
(j) Mechanism of cost control at design and construction stages.

The Organisation of Construction Economic Research

32 The organisation of construction economic research must be considered in relation to the main objective of the research which may be specified as follows:

(a) To provide a sound basis for policy decisions by Government, industrial organisations, and individual firms.
(b) To support the education of those entering the construction industry, especially builders and quantity surveyors.

33 An obstacle to the achievement of these objectives is the difficulty of attracting good quality economists into construction research. A subsidiary objective must thus be to engage the interest of some existing university economics departments in the subject, so that there might be some flow of graduates into research.

34 Applied economic research of such a variable and diverse industry as construction must include an important empirical component, requiring extensive data-collection and associated data-handling and analysis facilities. Such facilities are found in research stations rather than universities and the BRS has a long tradition of effective work of this kind. The Station has difficulty in recruiting suitable staff to lead this aspect of its work, but provided this difficulty can be overcome, there appears to be scope for the expansion of the Station's work in this direction, giving particular attention to the problems of Government.

35 There is little tradition of economic research in the research associations although they would seem to be well placed to undertake market surveys and forecasting exercises in which their industry has interest. It may be found, however, that the volume of such work would not generate a viable economic section in the Research Association, and that it is better seen as a part of an operational research activity. The exception to this pattern is CIRIA which it is to be hoped will develop a strong component of economic research in its programme when funds become available.

36 Economists are engaged in teaching in Departments of Building at a number of universities (Manchester, UCL) and colleges (Brighton, Brixton). There have been proposals for the establishment of a Chair of Building Economics at various times and places but none of these has been fruitful, because of a shortage of suitable candidates. Individual lecturers operating in Departments of Building need research support if they are to establish a teachable discipline. Such support could well take the form of a research unit working alongside the Department, of the kind operated by Professor Turin at UCL on problems of the building timetable.

37 There would appear to be a strong case for research units in each of the three subjects taken as headings for the review of research needs in this paper. Each unit might comprise 5–10 full-time research workers with ancillary staff. A research unit on micro-economics would be suitable for a Department of Building, while a unit on the construction product could well give strong support to the current developments in university education in estate management and quantity surveying.

38 The macro-economic research unit may best be attached to an existing university Department of Economics, preferably one with strength in this aspect of economic research.

39 University research in construction economics tends to lack financial support, since it does not qualify, as a rule, for grants from either SRC or SSRC. This anomaly could be corrected by the award of a limited number of research fellowships or research contracts on subjects of particular interest.

Conclusions

40 The paper has reviewed the existing level of construction economic research and has suggested (15, 23, 31) a number of subjects on which there appears to be a need for additional work. An outline for a suitable organisational framework is proposed comprising:

(a) A strong research team working on empirical problems at BRS.

(b) Increasing economic research by CIRIA—further enquiry into the possibility for such research in other research associations.

(c) Research units: in micro-economics at a Department of Building; in construction product at a Department of Estate Management and Quantity Surveying; and in macro-economics at a Department of Economics.

(d) Limited support for research in universities through research fellowships and contracts.

41 Following the Council's endorsement of this report, the Ministry has held discussions with a number of universities with a view to developing research in this area. Limiting factors are the availability of finance and of qualified workers interested in this field of study.

APPENDIX 6

Research Aspects of Construction Maintenance

(Based on a note by the Directorate of Research and Information, MPBW, May 1969).

The Characteristics of Construction Maintenance

1 Construction maintenance, comprising repairs, maintenance, and minor works to building and civil engineering structures, accounts for the expenditure of about £1650 million each year in the United Kingdom. About £380 million of this is attributable to self-help, divided between do-it-yourself work (approximately £220 million) and small directly-employed labour forces in the private sector (approximately £160 million). The balance (£1270 million) is executed by the construction industry. Large though the above figures are they must almost inevitably increase as the building stock increases; furthermore there is evidence of a substantial backlog of work requiring to be done; for example, the arrears of housing maintenance are estimated to amount to some eight or nine times the annual volume of work.

2 The principal technical characteristics of maintenance derive from its concern with the materials and techniques of construction of the past century and more which have created our stock of buildings. Often diagnosis of the causes of failure is required, calling for a high level of understanding of construction technology, while the work itself may require a much wider range of skills than new work. Much of maintenance is urgent in nature and the work content can only be assessed as the work proceeds, causing difficult problems in employment of management techniques of proven value in production applications. It follows that maintenance is demanding in both technological competence and management skill. In neither respect is it adequately endowed.

3 The nature of the private sector maintenance demand, fragmented, dispersed and ill-financed, has a profound effect on the structure of the industry. Half of all contract maintenance is executed by firms employing fewer than 30 operatives. The public sector demand, though better co-ordinated, is unusual in the high proportion of its work which is undertaken by direct labour.

4 Having regard to the economic importance of maintenance in relation to its neglect by both professions and academics and the lack of any coherent industrial base, the Minister set up the Committee on Building Maintenance to advise on the measures necessary to obtain significant improvement in its technical and economic performance. The Committee recently published an Interim Report, and has engaged in detailed studies on a number of areas. These studies, together with a Conference on Maintenance Technology and other consideration of needs for research and development, have provided the source material for this review.

5 The Committee regard maintenance work as the resultant of a system of some complexity. Social and legal institutions determine the framework of the system; for example, whether or not maintenance work is to attract tax relief or whether some particular sector of a market is to be subject to rent control. Design decisions exercise a more direct influence on maintenance and suggest that much current work demonstrates a failure to understand that investment now determines to a large extent a cash flow pattern for 60 years to come. The methods of property management (planned or random maintenance, preventive or corrective maintenance) also determine the nature and quantity of maintenance work required.

6 The existence of this system creates a dilemma; on the one hand it would be foolish to divide up materials research or economic studies in some arbitrary way and classify one

segment as main stream and another as maintenance research. On the other hand there is a need for integrative studies which examine the nature of the relationships underlying the maintenance system.

7 However, the above analytical framework is not well suited to a presentation of research requirements and a classification more closely related to research methods has been adopted. It is suggested that worth-while distinctions can be made between social and economic work in maintenance and also that research into physical aspects of materials performance can usefully be distinguished from design and operational problems. The current position and the opportunities for development offered by each of these subject areas is now discussed.

The Present Position

8 It was pointed out above that much of research and development into design, constructional methods, services, stability of structures and materials has relevance to maintenance, and indeed it is difficult conceptually to isolate maintenance research from construction research as a whole. However, a distinction can be made of those projects specifically directed toward the reduction of maintenance or to its more efficient operation.

9 In the sector supported by public funds some 10 per cent (£530,000) of the reported (and classifiable) total of £5,346,000 could be said to be specifically devoted to maintenance research in the sense described above. Of this £530,000 just over 70 per cent was concerned with the durability and quality control of materials and 20 per cent with studies of climatology and the performance of structures. The remaining 10 per cent was spread between maintenance of services and the operational methods, including plant, by which maintenance was undertaken. No similar analysis of expenditure by the private sector for 1966 can be given but around 8 per cent of the number of reported projects by that sector were specifically concerned with maintenance and durability.

Economic and Social Research in Maintenance

10 The paper on Construction Economics Research (Appendix 5) distinguished between the macro-economics of the industry, the micro-economics of the firm and the economics of the construction product. Maintenance economics forms part of the subjects treated under the first and third of these headings but the research needs are stated again here with somewhat different emphasis to give a comprehensive maintenance research perspective.

11 At the macro-economic level there is little relevant work on the factors which condition expenditure on building maintenance and the influence such expenditure has on the building stock, its economic value and necessary rate of replacement. Such research might provide a better understanding of the consequences for the national building stock of social and economic policies; the Rent Restriction Acts are an example of one field of application.

12 The effect of existing building programmes and policies on the future maintenance load has been studied by Dr Stone, but further research is required to establish an

effective predictive model. In part this is because the determinants of maintenance demand are not adequately detailed and the statistical data available is inadequate for model-building. A Working Group of the Maintenance Committee on the statistical situation has recommended a number of fields of research, including work on the national building stock and a detailed study of techniques of measuring labour productivity in maintenance.

13 The economics of the construction product require work to determine the actual, as opposed to the alleged, influence of cost limits on the maintenance characteristics of design. The techniques for discounting future payment are well-known and the cost-in-use method has been given wide publicity by the BRS. The use of these methods is still very limited, however, and further enquiry is desirable to ascertain the obstacles to their wider application. Methods to bring social costs and output losses into the calculations would also be of value. Consideration of repair/replace problems is central to maintenance economics and covers a wide spectrum from urban renewal to component replacement. The evaluation of social and environmental benefits is of particular relevance here. A related problem arises in the economics of short-life or adaptable buildings and their components. Such work could also have a direct and immediate effect on building design.

14 Serious research into maintenance economics scarcely exists and adequate coverage of the subject is urgently needed. It is, however, best seen as an inseparable part of construction economics and included in the remit of any Construction Economics Research Units which might be established.

15 The recent ECE Seminar in Warsaw on the management, maintenance and modernisation of housing revealed that throughout Europe, just as in England, very little social research has been done in this field although increasing interest is being shown in the problems involved. For example, an effective national housing policy must take full account of the determinants of property maintenance standards. Little is known of the influence of tenure systems on maintenance demand; while it is accepted that owner-occupiers deal less harshly with premises than tenants, no quantified evidence exists. Studies of alternative ownership and leasehold systems and of tenure systems on large properties might provide factual evidence to provide a basis for policy, for example, in the local authority field.

16 The motivation of building maintenance workers presents special problems, differing in many ways from production-line operatives, to whom most work in this field has been directed. It is commonly believed that building maintenance workers comprise mainly those who have opted out from the hurly-burly of bonus-chasing on new production, by reason of age or inclination. There are, moreover, special problems in applying conventional forms of incentives, deriving from the non-repetitive and unpredictable nature of much of the work. Such studies might well extend to examine the motivation of small maintenance contractors, many of whom show little interest in improvements in efficiency which might improve their profitability.

17 The review above suggests the following subjects for further research:

(1) The influence of maintenance policies on the building stock.
(2) The structure and determinants of maintenance demand.

(3) The extension of cost-in-use methods.
(4) The measurement of social benefits associated with repair/replace decisions.
(5) The economic characteristics of short-life buildings and components.
(6) Motivations of maintenance operatives and owners of small firms.
(7) The influence of tenure systems on maintenance.

Design and Maintenance

18 In traditional building, at its best, the designer could rely on the use of materials of well-tried properties and the support of building craftsmen familiar with the design details requisite for good performance in the prevailing conditions of exposure. In such circumstances the maintenance of buildings need not be a dominant preoccupation of the designer. A different situation prevails generally today in which designers employ a variety of new materials and components mostly of unknown performance and unfamiliar to the building workers who install them. In such conditions the designer must give explicit consideration to the effect of his choice of materials and detailed design on the likely maintenance of the building and convey instructions on installation clearly in the working drawings. This places a new emphasis on the need for the designer to have an awareness of the consequence of his decisions on the maintenance performance of the building.

19 To some extent manufacturers contribute to the resolution of these problems by providing materials and components of improved and defined maintenance performance. The influence of the Agrément Certificate is providing an increasing stimulus in this respect but there are also research requirements arising which are discussed under the section on technology below. The designer has to consider such materials assembled in buildings, however, and has to take into account the interaction between the materials employed, the influence of the user, and the particular conditions of exposure, etc., and thus needs to draw on accumulated experience to guide his decisions.

20 There is an urgent need for the systematic feedback of information on the performance of buildings to accumulate experience which can serve as a basis for design decisions. Feedback of data on maintenance costs and incidence is not sufficient by itself since an appraisal must be made of these data in relation to the conditions of use and exposure, taking into account the constraints under which the designer operated. Some attempts have been made to produce appraisals of this kind. BRS has published descriptive studies of the appearance of buildings and an architectural magazine made a number of attempts to publish critical commentaries of building details but was dissuaded from further efforts by threats of litigation. But the law of libel is not the most important obstacle to feedback. More important is the lack of a developed system by which the performance of the component parts of a building may be made known both to its designer and to the architectural world in general. Before any substantial expansion of activity is undertaken in appraising buildings, however, a good deal of development will be required in the methodology of such appraisals, which until now have relied excessively on subjective judgements of the appraisers.

21 Many building components break or bend when operated and there seems a great lack of adequate ergonomic data for their design. For example, a recent MPBW contract

on window fastenings had to begin with measurement of the forces exerted by various users, apart from the natural forces involved. This might indicate the desirability of an ergonomics unit concerning itself largely with building components.

22 The teaching of building construction in schools of architecture is still largely based on MacKay. To contribute to the new knowledge required and to stimulate the interest of educationists in the subject the Ministry has entered into contracts with some 17 universities and colleges for the collection and analysis of data on four topics: moisture in timber, actual falls achieved on flat roofs, movement in joints, and dirt deposition. The methodology and results are to be co-ordinated by BRS, GLC, and TRADA. The project in which CIRIA will participate in studies of corrosion in a large number of dispersed sites will also provide some of the basic knowledge required. Such arrangements are essentially *ad hoc,* however, and there is an evident need for a systematic approach to the problem.

23 The research needs suggested above may be summarised as follows:

(1) Development of methods of appraisal of buildings and feedback of experience to designers.
(2) Ergonomic studies of loads on buildings and components.
(3) Studies of performance of materials and design details related directly to design decisions.

Maintenance Technology

24 Almost the whole of existing research and development work by manufacturers has some maintenance content but the legitimate product orientation of such work leave significant areas unsupported, such as dirt adherence and frost action. Furthermore, the conditions of exposure of materials and components in buildings, arising from installation hazards, climatic exposure, and use are not covered by industrial research, and have been the traditional concern of BRS.

25 Performance studies need to take account of new conditions of exposure induced by trends in building design. For example, accumulating evidence indicates that materials giving a satisfactory performance at normal building heights often develop undesirable characteristics when used in high buildings and result in substantial maintenance expenditure. The use of new materials in conditions requiring long life is an additional feature of current practice.

26 The provision (see Appendix 4, para 5.5) for a new laboratory for research and testing of materials and components should satisfy the need for research on maintenance aspects of performance requirements which can find expression in standards, codes, Agrément Certificates and component development. There remains, however, a need to which the Committee on Building Maintenance attaches great importance for a service of the kind provided by the Scientific Adviser to the GLC, of product evaluation, sample testing, and site investigation. The influence on GLC buildings of this service, which has its equivalent in the laboratories of the largest contractors, provides an indication of the improvement in quality in construction which would be secured by a nation-wide service of this kind.

27 The Conference of Maintenance Technology held by the Committee on Building Maintenance and the studies of its sub-committee have identified a number of subjects requiring research. The mechanisms of environmental forces were seen to require substantial work; in fact only if such mechanisms were understood could satisfactory accelerated testing become feasible. The arguments for work on the basic properties of materials, performance in use and the development of new materials were considered to be of particular relevance to maintenance. Cleaning and redecoration is a substantial maintenance burden and a better understanding of the mechanism of dirt deposition and adhesion accompanied by the development of improved cleaning methods could save very large sums. Particular support is given to the case for widespread and systematic examination of the performance in use of materials of the kind described under the section on design.

28 Research on exposure conditions and the behaviour of materials under these conditions must be accompanied by a parallel effort aimed at providing materials and components with improved performance. Priority should be given to the development of maintenance-free surface finishes. About £300 million is spent each year on repainting buildings, a high proportion of which is attributable to labour costs which are likely to increase relative to other prices. The development of more durable paint systems, or surfaces of acceptable first cost which do not require painting offers prospects of substantial savings. A contract has been placed with the Paint Research Station for the study of painting systems for timber which will complement an existing CIRIA contract concerned with painting steelwork, but a substantial expansion of effort would seem to be justified economically.

29 Landscape maintenance can absorb large expenditure. MPBW alone spends £3 million a year on such work, much of it on grass-cutting. Experiments are in progress in the use of inhibitors on grass areas and a study of the total ecological consequences of such practices may prevent undesirable side-effects.

30 The research requirements described above are covered in large measure by the proposal for a new laboratory. The need for a national product evaluation and testing service, although strictly not a research requirement, is a means for applying research in practice which the Council might wish to support. Particular emphasis should be given in the maintenance context to the following items of research:

(1) Mechanism of dirt deposition and adherence in relation to improved cleaning methods.
(2) Development of more durable surface finishes.
(3) Methods of landscape maintenance, including ecological consequences of inhibitors, etc.

Operational aspects of maintenance

31 The management of maintenance has two principal aspects: property management and the management of the execution of maintenance. Improvement in property management depends principally on the application of economic and social research to the development of an appropriate strategy but at the tactical level there is scope for an operational research approach to such problems as inspection frequencies and preventive

or corrective maintenance policies; a good deal of work has been done by operational research groups in maintenance engineering but these studies place too much weight on plant downtime losses to be directly applicable to building maintenance.

32 It is generally recognised that both aspects of management would benefit significantly from a feedback system providing information on costs and incidence of maintenance items. Studies made at BRS, MPBW, and elsewhere have developed a methodology for handling such data but the basic information is currently very difficult to obtain. The Ministry has commissioned Bath University of Technology to undertake a study of the problems of establishing a national data-bank for such information and a pilot scheme is being conducted to establish the form and feasibility of a Building Maintenance Cost Information Service. The availability of such a data-bank would facilitate research into the influence of design and maintenance and statistical aspects of materials durability.

33 The execution of maintenance poses difficult problems of production scheduling and control, depot location, use of mobile depots, stores policy, supervisory ratios and similar problems which might yield to operational studies.

34 Within organisations such data could provide the basis of a maintenance management information system which would provide a means of evaluating policies on budgetary control, maintenance standards, etc., as well as giving comparative analysis of managerial efficiency. Initial studies of this kind now being made by a team at the London School of Economics based on some of the Ministry's maintenance area indicate that an expansion of research effort would be justified.

35 The small scale of most maintenance contractors and the fragmentary character of demand creates many operational problems. For the client, these include the selection of contractors, the form of contract, credit facilities and control of quality of work. Contractors are generally too small to employ an adequate accounting service and are especially vulnerable to bad debts. The Ministry has commissioned an exploratory study by the Research Institute for Consumer Affairs into the relationship between small-scale building owners requiring maintenance services and the contractors who supply the service. The Ministry is itself experimenting with new forms of contract, including a lump-sum price for specific minor maintenance items in a group of buildings, which may justify wide application. Research into problems of this kind calls for a combination of industrial economics and building technology and could be seen as suitable for the developing research interests of colleges of estate management.

36 Studies of operative skills in building maintenance were made by BRS in the course of its major study of the subject for the National Joint Council. Such studies need to be extended to deal with the training needs for multi-skilled operatives. It will be essential, however, that any such ergonomic studies should be preceded by an analysis of maintenance tasks, and that the location of such studies should provide both ergonomic and building technology skills.

37 The headings for research suggested above include:

(1) Operational research studies of property management.
(2) Studies of causes of maintenance based on analysis of feedback data on maintenance incidence.

(3) Development of a maintenance management information system.
(4) Contractual and organisational problems of building owners and contractors.
(5) Operative skills for maintenance.

The Organisation of Maintenance Research

38 The foregoing review of research needs in building maintenance serves to confirm the earlier observation of the difficulty of drawing a distinction between maintenance research and mainstream economic or physical research. Research dealing with problems peculiar to maintenance lies mainly in the areas of operational and social studies.

39 The proposals made in other CRAC reviews dealing with materials and components research and testing and with economic research thus make provision for an expansion of effort in aspects of maintenance. Nevertheless it is important that maintenance should have some permanent institutional framework for relevant research to ensure that maintenance problems are kept in focus and to provide a stimulus to a subject which has for long been intellectually underprivileged.

40 The operational and social problems of maintenance provide the appropriate subject area for the establishment of such a focal point for maintenance research. The organisations currently active in this subject area which might be considered as a potential base for expansion include BRS, the London School of Economics, Strathclyde University (OR Department), Bath University and the Local Government Operational Research Unit. The main requirement is for close association with property managers and maintenance contractors, together with the ability to tackle operational problems calling for a wide range of disciplines, including building technology. There is no obvious educational outlet although it may be hoped that teaching in estate management will reflect increasingly the development of more quantitative methods.

41 The BRS offers the natural starting point for a unit of the kind envisaged since within its Production Division it contains the relevant range of skills and can call on support from other divisions in other aspects of building technology. It would be important, however, if such a unit be established at the Station, that it should be given a distinctive entity and be recognised by property managers and others as centrally concerned with their problems. The LGORU has the particular advantage, however, of close contact with authorities who provide a natural outlet for research of this kind. Property management is a major responsibility of local authorities and the degree of similarity of their problems facilitates the application of research done on a collective basis. The scope for research in this subject area is sufficient to allow two units to operate without overlapping, and it is suggested that the LGORU should be encouraged to develop a coherent maintenance research programme, co-ordinated with the work at BRS and elsewhere. The development of a Building Maintenance Cost Information Service may provide an additional base for operational research. If such a service develops there will be a case for considering its amalgamation with the BRS unit in three to five years' time. It would then constitute a Property Management Research and Advisory Institute, incorporating a cost information service.

42 The principal outlet for maintenance research through education is by influencing the training of designers, mainly architects. A good deal of interest has been stimulated

by the performance studies commissioned by the Ministry, and there is scope for expansion by placing research contracts for similar studies in selected schools of architecture and building.

43 The main directions for maintenance technology have been set out in Appendix 4 which sees responsibility for the development of improved materials and components as falling mainly to research associations and private industry.

44 Discussions with the Building Materials Working Party of the Research Associations and with individual firms are continuing, and these can take account of the special emphasis to maintenance problems. The additional requirement brought forward by this paper concerns a national advisory service in materials technology. Such a service would provide research with a powerful mechanism for implementation. It would need to have close association with both the new laboratory for materials and components research and testing (see 26 above) and the information and advisory services.

APPENDIX 7

Research and Development Needs in Computer Application

(Based on a note by the Directorate of Research and Information, MPBW, September 1969).

1 In May 1966 the Minister appointed a Committee on the Application of Computers in the Construction Industry (CACCI) to review present and potential computer applications and to advise the Ministry on the need to co-ordinate existing effort and to promote new advances. Part of its task is the identification of research and development needs. The Committee, though well aware of the need to look at the process as a whole, has found it preferable to conduct most of its preliminary studies on a disciplinary basis, by sub-committees or working parties. This paper draws on the work of the Committee, some of which is, necessarily, at an early stage, and any statement of it must therefore be of a provisional character.

Current Research and Development

2 For the purpose of this paper research in computer applications is defined as that research whose purpose is the variation of procedures, or the devising of new procedures, leading to the employment of computer techniques at any point of the design and construction process. This may include, where necessary, studies or experimental application. This definition excludes work in which the computer is employed solely as an aid to calculation, or as a means of speeding up an existing procedure; research in computer systems and programs, although it may indirectly benefit the industry; and research in construction subjects whose results find expression, simply as a medium of convenience, in computer programs. An analysis of research and development projects active in 1968, based on the returns to the Survey of Construction research and development for that year, is given in the table on page 56.

It is evident that the projects in central Government are much more substantial than those in universities. The projects, virtually without exception, deal with specific problems contained within the present compartmental structure of the industry. Nearly three-quarters of them are concerned with design or analysis in some form or other.

Research and Development Needs

3 In the longer term, the impact of the computer must promote the integration of the construction process, but in the shorter term developments are directed principally at a procedure-for-procedure substitution and should leave the options open for more radical changes. It is thus convenient to consider research needs initially under the headings of the various roles—structural engineering, contracting, etc., but to include a section on the construction process dealing with the research crossing existing boundaries, especially in design.

Civil and Structural Engineering

4 Computer applications to civil engineering, principally road and bridge design, drainage networks, etc., are the responsibility of the Ministry of Transport which has an active computer group developing suites of programs in association with industry. Interest in CACCI has been concentrated on applications to structural engineering generally.

Projects active in 1968

Number of projects

Type of Work	Public Sector				Private Sector		Total
	Central Govt.	Local Govt. and Public Authorities	Universities, etc.	Research Association	Construction Industry	Computer Industry	
Design, architectural	—	1	21	1	—	—	23
Design, civil and structural	2	4	61	—	22	2	91
Design, services engineering	4	—	27	1	2	3	37
Structural performance	—	—	10	2	3	—	15
Quantity surveying	2	2	—	—	2	—	6
Management	2	—	12	—	3	—	17
Information coding and handling	—	—	3	2	2	—	7
Computer techniques	1	—	15	2	2	3	23
Total number of projects	11	7	149	8	36	8	219
Expenditure in 1968 (£000)	200	20	240	50	Not available		

5 Structural engineers were among the first enthusiastic computer users and many programs exist for structural analysis. The NCC program index includes 600 programs of which six are said to be usable generally. The extension of computer use from the few large firms to the profession generally depends on the provision of suites of programs in a form capable of general use on a wide range of computers.

6 On the advice of CACCI the Ministry is developing an integrated software system for structural engineering, GENESYS. This is essentially a program-handling system which specifies standards for program-writing and accords the engineer considerable flexibility in the way in which he can handle sequences of programs within the computer by means of a command language reasonably close to English. It will function on a wide range of computers and so encourage the interchange of programs and co-ordination of practice within its area of application. It should become available for general use at the beginning of 1971.

7 Suites of problem-solving programs must be written for operation with GENESYS and an initial set is now being developed. It is proposed to include analysis programs for a wide range of structural frameworks as well as programs dealing with the detailed design associated with the preparation of working drawings. This problem is at the interface between design and construction. The solution offers immense potential rewards but is likely to change many existing conventions and will require intensive study.

8 GENESYS provides a basis for the co-ordination of the research and development required in this field and offers prospect of application to many other areas in computer-aided design. It will require further development to improve its efficiency and scope and to extend the range of problem-solving programs. A GENESYS Centre has been formed at Loughborough University with a small nucleus of staff, to provide the necessary information, education and development services. It will be closely associated with the current development work both on the central system and the problem-solving sub-systems so that it can give an effective service as soon as they are released for public use.

9 Little progress has been made in the use of computers for design as distinct from analysis of tentative solutions. The problems here are close to those of architectural design and will require the development of methods of interrogating the computer which are discussed in more detail below.

Engineering Services

10 Developments in this area have tended to be on an *ad hoc*, unco-ordinated basis, using a variety of design techniques and computer languages for different machines and based on alternative development philosophies. There is confusion in areas where programs overlap and a dearth of factual information, both technical and financial, on which to judge the efficacy of existing as well as new programs. In the circumstances many practitioners currently prefer to develop their own exclusive programs. A new Sub-Committee of the CACCI will provide the essential co-ordination and consider the advisory service required.

11 Most of the existing programs in the services field are concerned with various aspects of design including calculations of heating gains and losses, equipment, plant, pipe and duct sizing, lighting calculations, cable sizing, and total energy considerations for alternative plant types and combinations, etc. The programs concerned with air-conditioning

system design are a vital part of this list both because of their potential economic advantage and because they highlight the interplay of parameters affecting the architect and the engineer jointly. The Ministry has commissioned the HVRA to review and evaluate these air-conditioning programs, taking into account existing commercial programs.

12 Both the APEC Group in America and COSTIC in France have made significant progress in developing an integrated suite of design programs. Reports from COSTIC are that their pipe and radiator sizing programs cost NF 0·5 million to develop, but potential saving to the designer using the COSTIC service is said to be some 10 per cent compared with manual calculation. The use of the program is increasing rapidly, business in the first five months of 1969 equalling that during the whole of 1968. Equivalent development in this country is urgently needed, though a direct adaptation might not be desirable. HVRA are undertaking a comparison between the COSTIC pipe sizing program and the ICSL equivalent on specific local authority projects and will take account of comparisons between manual and computer methods in progress in the Ministry.

13 The Ministry is also active in the development of interactive programs which enable alternative design solutions to be explored and optimum installations chosen on the basis both of technical performance and gross annual cost. Programs in course of development cover:

(i) The relationship of heat gains, losses and system operating costs to building shape, size, orientation, and fenestration.
(ii) The optimisation of pipe insulation thickness.
(iii) Provision of lift cars for high rise buildings.
(iv) The design of fluorescent lighting installations.
(v) The optimisation of district heating and water supply mains routes to produce the most economical reticulation system (by HVRA).

In addition, the Ministry is working conjointly with the BRS on a series of programs to incorporate the latest data and techniques on the thermal performance of buildings, including calculations of peak internal temperatures, cooling load requirements, and operating cost comparisons. The extensive and diverse mechanical and electrical work carried out by the Ministry provides an excellent base for the development of computer applications in association with BRS and other research bodies and it is hoped to increase the resources devoted to this work.

Architecture

14 The present position in the profession is that very few computer programs are available for use in offices: those few cover isolated quantifiable aspects of design, such as scheduling, the use of simple operational research techniques, the analysis of environmental factors, but they are largely unconnected and make little impact on the total design task. A few projects are attempting a more comprehensive use of the computer in less complex design situations, notably a project at West Sussex County Council which is supported by IBM, some universities and other sources. The Ministry is collaborating with the National Physical Laboratory on a project based on system-building

for the Ministry's own building programme and is supporting work at the Centre for Land Use and Built Form Studies, Cambridge, and at the Architectural Research Unit, Edinburgh, the latter in collaboration with Scottish Development Department and the Scottish Special Housing Association. The Ministry's commitment on these and a few small projects is of the order of £30,000 per annum, including staff costs. Apart from this, there are some initiatives within offices and a certain amount of exploratory work within Schools of Architecture, but resources are inadequate and co-ordination is informal and ineffective.

15 The extension of application of computers to scheduling and other information handling tasks in design offers prospect of savings but depends on systems analysis rather than research and development. An urgent need here is to incorporate standard regulations and briefing data within the design data handling system. Analytical programs, providing the evaluation of the design in terms of some aspect of the performance of the building, such as daylighting, acoustic insulation, roof drainage, etc., often require the formulation of mathematical models, requiring further research and development. These separate evaluation programs need to be co-ordinated to provide a comprehensive analysis of performance, taking account of the interactions between the various factors involved. The need to interrogate the computer in making use of analysis in a design context gives rise to the need for development of lightpen techniques and programs suitable for use on remote terminals.

Quantity Surveying

16 The computer has clearly a major contribution to make to quantity surveying by exploiting its capacity for computation and data collation, and more than 20 systems for producing bills of quantity by computer have been developed. The quantity surveyors are central to the communication system and their use of computers depends critically on the outcome of the Working Party on Data Co-ordination, established by the Minister's National Consultative Council, which has the task of advising on whether a co-ordinated system is feasible and, if so, the action required to implement it.

17 The Working Party has already initiated various studies and will be going on to decide the research required to support a communication system. It is preferable to await this general statement of research needs rather than anticipate it now, but certain specific research problems derive specifically from aspects of the computer's capacity to serve adequately the needs of quantity surveyors which justify mention here. These problems concern mainly the man-machine interface—such as the form of coding suitable for taking off quantities from drawings, but they also extend to the capacity of the computer itself, such as the choice of data structure for the very large files (such as libraries of bill items) and the provision of a cheap form of visual display and recording, also discussed in paragraph 24.

18 The Sub-Committee of CACCI on Quantity Surveying has these research needs under review and is also considering how the information generated by the quantity surveyor can be used more effectively by architect and contractor.

Contracting

19 Project management, extending from tendering to final account, has many special features in construction, deriving from dispersal and changing site locations, the varying personnel and production tasks. The management techniques on which computers are employed include PERT network planning, resource allocation (often in association with PERT), line of balance, cost control. Although success with some of these techniques is contingent on use of the computer it seems best here again to deal separately with research needs for management as a separate subject, absorbing the computer applications within it.

20. It should be noted, however, that such consideration of management techniques draws fully on the capacity of the computer. Many new developments of management information systems, for example, are made possible by the computer. Construction is likely to offer special difficulties for the introduction of such systems and may require a provision of standard library of operational descriptions for building work and the development of methods of materials control on site, *inter alia,* before effective progress can be made.

21 Problems which may be considered specifically computer-based include such matters as data capture on site. This refers to methods for recording matters concerning labour (principally) and materials so that they can be transferred without further human intervention. Methods of mark sensing have been developed at BRS for this purpose but further development is needed for a system to be widely applicable in the industry.

22 A Sub-Committee of CACCI on the application of computers in the construction of buildings has made a proposal for a centre similar to the GENESYS Centre serving the interests of contractors. This has been discussed with the industry at a series of seminars convened jointly with the NFBTE. The decision on this proposal itself must depend on the support coming from industry but also on developments in the services being offered within the industry itself. There have been many indications recently of an enthusiasm within the industry to market certain computer applications and provide a service based on them, including the combined Mowlems/Costains services to contractors and Capital Cities Computer Utilities.

The Construction Process

23 The use of computers to secure the integration of processes, sometimes in different organisations, is already evident in a number of instances. The specification of requirements for windows in Herts. County Council schools is recorded on punched tape which provides bills of quantity documentation and also controls the production facilities in the factory. At West Sussex County Council and in certain building firms, the design, cost planning and estimating stages are linked and draw on a single pool of information. The natural extension of this trend would consist of a computer to which all designers and contractors concerned with the project would be linked with terminals in offices and on site. All projects data would be referred to the computer which would provide the information required. The first requirement for such an integrated system is a rational system of information flow and this is now under consideration by the Working Party on Data Co-ordination which will be considering the research and development requirements.

24 There are developments in the use of computers for design which affect all professions and can best be considered under this heading. Greater use is envisaged of interactive graphics devices, and suitable operating systems need to be developed for the cathode ray tube and lightpen; the storage tube, a cheaper adjunct to the CRT, should be evaluated for design and basic software should be produced for it. Work is needed on hardware and software for advanced graphics, including half-tones, colour and three-dimensional images. The large amounts of varied data involved in design necessitate the development of suitable mass filing systems and investigation of dynamic data structures.

25 Mathematical modelling techniques are recognised as a major tool of the designer and although these have been used extensively in analysis, there is a need to apply them directly in design. This will require exploration of optimisation techniques, simulation and learning models.

Organisation of Research and Development

26 The Committee on the Application of Computers in the Construction Industry has given first priority to action aimed at overcoming barriers to application in the industry. Two such barriers are ignorance of computers, particularly among upper and middle management; and lack of co-ordination of the development of software. The first was considered by a conference called be the Committee on education and the computer. It gave emphasis to the need for education in computers for those in mid-career and recommended the setting up of a special college for this task.

27 In a fragmented industry such as construction, few organisations are large enough to afford to develop their own software and the widespread use of computers must depend on general availability of suitable programs. This software must conform to agreed forms of input and output, be compatible with the computers in common use in the industry and be accompanied by an adequate users' manual. The Institution of Structural Engineers has given the lead in this respect and the standards they determined are now given expression through GENESYS. There is an urgent need to follow this example in other areas of application.

28 The Committee thus proposed the establishment of a Construction Industry Computer Centre (CICC) which would be devoted specifically to overcoming these barriers to the use of computers in construction. The proposal envisaged that the Centre would review existing computer programs and co-ordinate the development of suitable suites of programs for the various areas of application; would give assistance and advice to firms new to computer applications; advise computer users about the availability and suitability of programs; identify current problems and develop existing programs (or prepare new ones) to solve them and perform a general education function. Such an organisation could be seen as a specialist extension for a particular industry of the function of the National Computing Centre for industry generally. The Ministry has accepted in principle that such a service should be provided and is currently exploring methods of doing this.

29 It is an essential feature of the proposal that CICC should embrace the various disciplines engaged in construction so that the computer programs can reflect a collective approach to the construction process. It is intended that the GENESYS Centre should

form part of CICC and may well constitute the nucleus for its growth. Subject to the views of the industry the centre for contractors' work would also form part of CICC.

30 The Centre should draw income from its programs and although an initial staff of 25–30 has been proposed, demand for its services could generate rapid growth. Given this demand, the Centre would be the logical base for much of the development work required in co-ordination and consolidation of programs and could serve as a focal point for the co-ordination of research and development for computer applications to construction generally. Much of the short-term development for quantity surveying and contracting applications should fall to the Centre. Arrangements for longer-term research in these areas will need to take account of the recommendations of the respective CACCI Sub-Committees. The needs for design research are sufficiently clear to enable a suitable framework to be proposed.

31 The organisational arrangements for longer-term research and development can best be considered in the context of computer-aided design generally rather than in terms of the separate professions. The provision of analysis programs can best be achieved by the association of active research workers with those associated with practice. The association of BRS and HVRA with the Ministry's Directorate of Engineering Services Development is an example of collaborative working of this kind. The priority BRS is to give to systematic design should provide further scope for associations of this kind. A number of schools of architecture are also active in models for building and, provided suitable links with practice can be found, it is proposed that a limited number of centres, say three, should be given support by research contracts.

32 Development of computer-based methods for building design, starting with specific building systems but extending to traditional building, is well under way, together with the research into data structures, interactive graphical methods, etc., needed to support this development.

33 The three centres of activity established by the Ministry at Cambridge, Edinburgh (in association with SSHA and SDD), and NPL have access to the most advanced computer knowledge in the country and their links with architectural practice and problems are strong. They constitute natural points of growth for the necessary expansion of work in this area. There would be advantage in associating the development at West Sussex with the Ministry's programme and a suitable co-ordinating machinery might be provided by the sub-committee of CACCI on architecture. The work at these centres is likely to generate fundamental problems calling for research which may well be capable of resolution by the centres themselves. There may well be a need, however, to draw on specialist knowledge and research skills available elsewhere, such as expertise in graphical techniques at Imperial College, by awarding specific research contracts.

34 The more exploratory investigations of design methodology must depend on finding a suitable venue for the research. Bristol University and Edinburgh University have active research in this area with architectural affiliations and it is suggested that limited support by research contract might well be justified by the potential significance of the research, although short-term benefits are improbable.

35 It is envisaged that some £200,000 will be expended on the initial development of GENESYS and that some £30,000 per annum will be required to finance the GENESYS Centre. An additional £30,000 per annum is being expended currently on the three computer-aided design projects. It is estimated that £150,000 per annum would be required to support the research programme on computer-aided design suggested above.

APPENDIX 8

Examples of sponsored work by CIRIA

Since 1962 more than 150 projects have been undertaken of which 77 will have been reported by the end of 1970. Sixteen of the current 51 projects are financed by earmarked contributions.

The economic value of research on construction is very difficult to assess but it is estimated that the Association's past research enables the industry to save some £10 million a year or about 30 times current annual cost. Of the expenditure on completed projects, 40 per cent has provided substantial commercial value, 50 per cent a significant increase in knowledge, and only 3 per cent has been abortive.

Floor loadings (Building Research Station)
A survey of floor loadings in offices and retail premises has produced frequency-intensity data on the actual loadings that occur in practice. The results will provide the basis for future design loadings.

Wind effects (Electrical Research Association)
This is a large and important project financed jointly by a number of organisations with a special contribution from MinTech. It includes studies of wind structure and the behaviour of wind-sensitive structures.

High strength steel in reinforced concrete (Cement and Concrete Association (static loading) and Building Research Station (fatigue))
The research is aimed at providing data for the prediction of crack widths and spacing under static and repeated loads. The results have included a general hypothesis for the cracking pattern in concrete members.

Behaviour of large-panel structures (John Laing Research and Development Ltd and Imperial College)
At the time of the Ronan Point collapse the Association was considering a research project on the design of large-panel structures with special reference to jointing, but delayed its implementation until the Tribunal Report appeared. Only slight modifications to the programme were required and the work is now in progress supported by five of the large system builders and MPBW.

Elevated road structures (Cement and Concrete Association)

Load distribution in bridge decks (University of Dundee)
These two complementary projects comprise a substantial research programme aimed at producing a general design procedure for elevated roads.

Design of hoppers and silos (John Laing Research & Development Ltd)
The purpose of this research is to provide designers with data on the dynamic pressures induced while hoppers and silos are being filled and emptied. Tests are being made on the full scale on models.

Friction-grip bolts in structural steelwork (University of Bristol)
This research has shown that in the design of bolted joints the relaxation of bolt tension, the condition of the contact surface and the strength of the cover plate material have to be taken into account.

Painting and protecting structural steelwork (Paint Research Association)

This research has been concerned mainly with the preparation of steel surfaces for painting and has shown that roughness and cleanness are key factors in ensuring paint durability. A surface cleanness meter has been developed, patented, and marketed under agreement.

Operational research on steelwork fabrication (Welding Institute)

This study was initiated to examine the work flow involved in fabricating steelwork in order to reduce cost. A system of control has been proposed that promises to reduce lost time.

Working loads on adjustable props (University of Birmingham)

Many accidents occur due to the failure of temporary props and this research has shown how a realistic assessment of their strength in practice can be made. It has also provided guidance on erection and some improvements in prop design.

Wet weather earthworks (Road Research Laboratory (first phase)) (University of Sheffield and Lehane, MacKenzie and Shand Ltd (second phase))

This research is concerned primarily with the technical management of earth-moving machinery and studies of performance. The work consists chiefly of site studies. Useful results have already been obtained.

Requirements for pumping concrete (Taylor Woodrow Construction Ltd)

The research was undertaken to provide guidance to contractors on the characteristics of concrete necessary for successful pumping, on pump performance and on the effects of pipe sizes and lengths.

Use of power tools in house construction (National Building Agency)

This survey was conducted to determine the extent of the present usage of power tools in house building and to identify operations where costs could be reduced by the greater use of power tools.

Economics of pipe networks (Queen's University, Belfast)

This research has resulted in a computer program for the design of pipe networks, to optimise new networks and to determine the most effective means of improving those in existence. The program has been made available through licensed bureaux.

Flow through partly-lined conduits (Imperial College)

This project consisted of laboratory research and full-scale tests on a long rock tunnel with concrete invert. The results allow the cost of rock tunnels to be reduced by several thousands of pounds a mile.

Oscillation of piles in marine structures (British Transport Docks Board, National Physical Laboratory and John Mowlem Ltd)

An important difficulty has recently occurred in jetty construction when fast flowing tides created unacceptable vibration in the supporting piles. This research has been financed by earmarked contributions and is being carried out on the full scale. First results indicate that a solution will be found.

Civil engineering bills of quantities (University of Manchester Institute of Science and Technology)

The aim of this research has been to develop improved bills for civil engineering quantities. The results in the form of experimental bills are being tested in practice.

Decompression sickness and bone necrosis in compressed-air workers (In co-operation with the Medical Research Council, University of Newcastle and various members of CIRIA)

Bone necrosis is a dangerous crippling disease in compressed-air workers and the research was aimed at producing a decompression procedure to reduce its incidence. The new procedure has resulted in a reduction of about 70 per cent in normal decompression sickness and the indications are that bone necrosis will be reduced by a similar proportion.

Air diving tables (Ministry of Defence (Navy))

The Association's involvement in decompression research and in the setting up of the Underwater Engineering Group has resulted in CIRIA being appointed the agent of the Ministry of Defence for the release to civil industry of its air diving tables (which are in part based on the decompression research).

A committee has been formed to ensure that the tables are released only to those firms capable of using them and for establishing safety precautions and technical feed-back of experience.

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